6.3 Weeds, pests and diseases

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6.3.1 Introduction

Factors influencing crop production can be divided into three schematic groups: yield – defining factors such as radiation; yield – limiting factors, such as the availability of water and plant nutrients; and yield – reducing factors, such as weeds, pests and diseases. Yield – defining and yield – limiting factors have been treated in previous chapters. In this section emphasis will be placed on an analysis of yield – reducing factors.

Yield reductions caused by weeds, pests and diseases are common in agricultural practice. The actual yield reduction varies with the crop, soil, climate, current weeds, pests and diseases, crop rotation, the level of control and many other factors. The effects of weeds, pests and diseases can be taken into account by multiplying the result of the preceding production estimate by a factor one minus the mean proportion of loss. The result is only a very rough estimate of the effects of weeds, pests and diseases without discriminating between production levels, climatic conditions, etc. Estimates of yield losses obtained from experiments are highly variable, as shown in Figure 68, giving the relation between the relative yield without weed control and the frequency of its occurrence for transplanted, flooded rice (Van Heemst, 1979). The expected mean, m_e, and its standard deviation, q_e, are 0.51 and 0.23, respectively. The expected mean is a crop characteristic and the high value of q_e is an expression of the variability in weed species, weed density and the variability in the crop itself. The variability in loss estimates due to pests and diseases is of the same order of magnitude. Therefore, correcting crop production estimates using this type of information yields only a rough approximation of reality and is not very satisfying. Hence a sounder method of evaluating yield losses should be developed. In this section a methodology is suggested for assessing the effects of weeds, pests, and diseases in a more detailed way by the use of simple explanatory models. On the basis of such models it may be possible to relate the impact of weeds, pests and diseases to the production level that is pursued.

6.3.2 Weed models

Damage to crops through weeds is essentially caused by the competition for radiation, water and nutrients between weeds (unwanted plants) and the crop. However, the degree of weed control in many crops in high – input farming systems, seems to be poorly related to the risk of competition. In such situa-

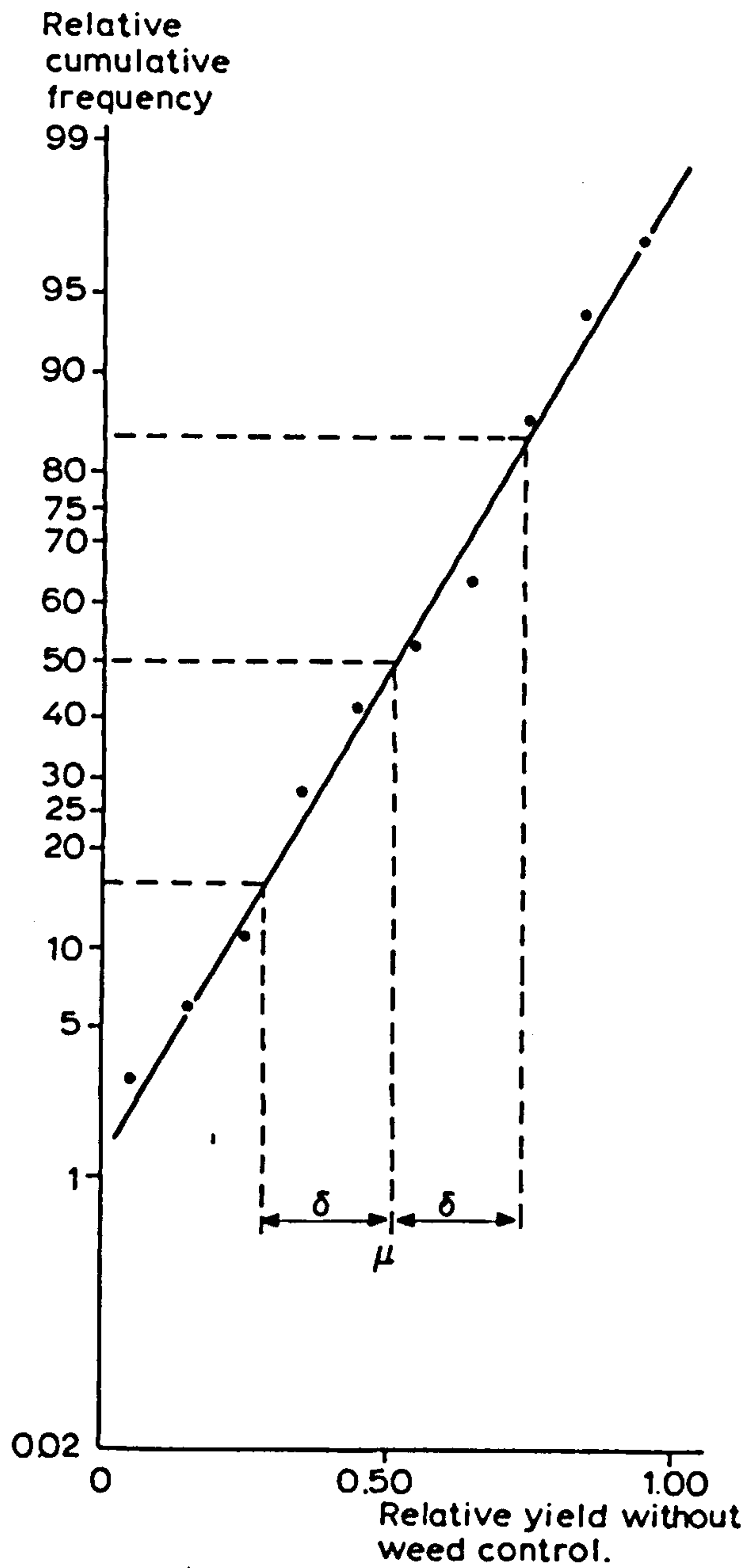

Figure 68. The relative cumulative frequency of the relative yield of transplanted flooded rice without weed control, plotted on normal probability paper.

tions other considerations are of greater importance, such as loss of quality of the harvested product, unfavourable effects during harvest and the need for weed suppression to a level below competition risk in view of crop rotation schemes. Here, only competition aspects will be treated.

Some theoretical aspects

If it is assumed that the physiological characteristics of the weeds and the crop are similar, the growth rates for weeds and crop growing in a mixture can be described by:

$$G_c = (L_c/(L_c + L_w)) \cdot G_t \text{ and } G_w = (L_w/(L_c + L_w)) \cdot G_t \quad (100)$$

or $G_c/G_w = L_c/L_w$

where

- G is growth rate (kg ha^{-1} d^{-1})
- L is the leaf area index; the subscripts c, w, t refer to crop, weeds and total, respectively.

If the growth rate for both crop and weeds depends only on the total leaf area index, the ratio between L_c and L_w is maintained during the entire growth cycle. The final total dry matter production is thus distributed over crop and weeds in proportion to that ratio, still under the assumption of identical physiological characteristics. This implies that the damage of weeds to a crop can be derived directly from the ratio of the leaf area indices of weeds and crop at the onset of competition, i.e. at emergence. As the growth of seedlings follows an exponential pattern (Exercise 10), it can be described by:

$$Y_t = Y_0 \cdot e^{rt} = N_s \cdot W_0 \cdot e^{rt} \quad (101)$$

where

- Y_0 is total dry matter yield at time 0, i.e. emergence (kg ha^{-1})
- Y_t is total dry matter yield at time t (kg ha^{-1})
- N_s is the number of seedlings
- W_0 is the average weight of an individual seedling (kg)
- r is the relative growth rate (d^{-1})

Hence the relative start position of crop and weeds is defined by the number of seedlings and their weight at the start of the competition. Even under the crude assumption of identical growth characteristics, some general conclusions can be drawn from this description. Planted and transplanted crops will be less susceptible to weed competition than seeded crops because of their relative advantage in leaf development. Small-seeded crops, like sugar-beet, are more susceptible than big-seeded crops because the weight of the seedling is highly correlated with seed weight. Slow germinating species have a disadvantage in comparison to fast germinating species.

Crops and weeds

Clearly, the assumption of identical characteristics for crop and weeds does not hold in many situations. An important difference between a crop and weeds may be their maximum height and the time needed to reach that height. When species differ in height, the tallest species will have an advantage over

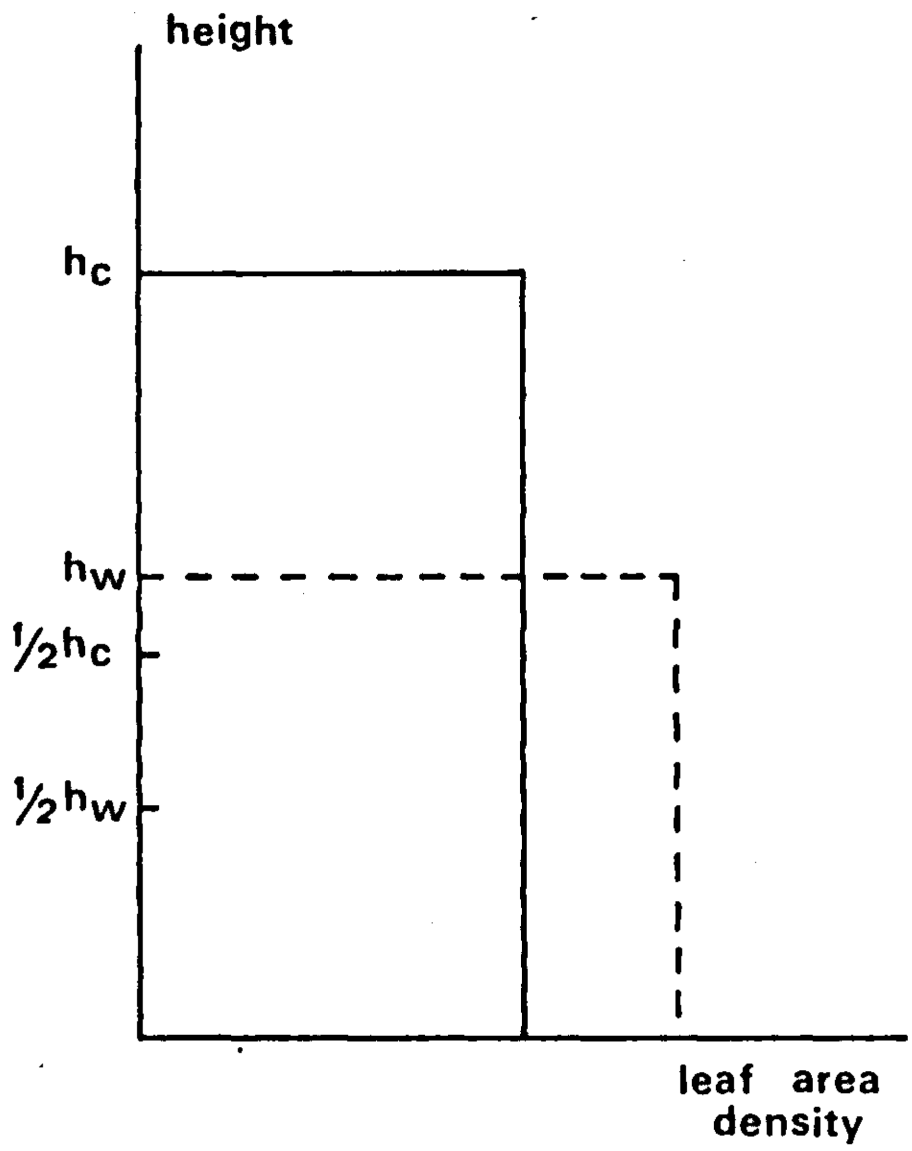

Figure 69. Schematic representation of leaf area density distribution for a mixture of two crops of different height. h_c and h_w represent the height of the crop and of the weeds, respectively.

the shorter one because of shading, even if their leaf area indices are about the same. A quantification of the effects of height differences is given by Spitters & Aerts (1983).

Figure 69 presents an example in which the weeds have reached a height H_w and the crop a height H_c. The leaves of a species are assumed to be evenly distributed with height and its growth rate to be proportional to the leaf area index and the radiation intensity at half the height, H_h, of the crop or the weed. The radiation intensity at H_h is a function of the leaf area above H_h (Section 2.1). The extinction of radiation can be described by:

$$I = I_0 \cdot e^{-k_e \cdot L} \qquad (102)$$

with k_e the extinction coefficient and L the total leaf area index above the point of measurement.

The leaf area index above H_{hw}, half the height of the weeds, is:

$$L(H_{hw}) = L_w/2 + ((H_c - H_w/2)/H_c) \cdot L_c \qquad (103)$$

If H_w is more than double H_c the last term has to be omitted, because there is no influence of the crop at a height H_{hw}. The leaf area index above H_{hc}, half the height of the crop, is:

$$L(H_{hc}) = L_c/2 + ((H_w - H_c/2)/H_w) \cdot L_w \qquad (104)$$

The growth rates can now be described by:

$$G_c/G_w = L_c/L_w \cdot e^{(-k_e \cdot (L(H_{hc}) - L(H_{hw})))} \qquad (105)$$

$$G_c + G_w = G_t \qquad (106)$$

Exercise 85
Calculate the ratio of the growth rate for weeds and crop, using Equations 105 and 106, for $H_w = 1.2$ and $H_c = 0.8$ and $L_w = L_c = 1.5$ and for $H_w = 0.8$ and $H_c = 1.2$, with $k_e = 0.65$ in both cases.

The ratio between the growth rate of the crop and that of the weeds will now also vary in relation to their heights. A description of the increase in height with time is necessary to calculate the result of the competition process in terms of partitioning of total dry matter between crop and weeds. In Table 71 the equations are given to calculate the growth of crop and weeds over time. The growth conditions are assumed to be constant for the sake of simplicity. The results are given in Tables 72a and b.

6.3.3 Weeding

In almost all agricultural systems, removal of weeds by hand or by the use of herbicides is common practice. Because our main interest is crop production in developing countries, hand weeding will be treated in some detail. Before planting or drilling a new crop, the land is cleaned from weeds as part of the seedbed preparation. The crop is planted and after some time the farmer will judge the need for weeding. As competition for radiation between crop and weeds will only become significant at a total leaf area index above 1.5, weeding is supposed to take place if the total leaf area index, L_t, exceeds 1.5 and the proportion of weeds in L_t is higher than 0.2. Weeding will remove nine – tenths of the weed biomass, reducing at the same time its average height to one tenth. Tables 73a and 73b show the results of the competition when weeding is practiced for a crop with a relatively high competitive ability such as wheat and for a crop such as sugar – beet, which has a much lower competitive ability.

Table 71. Basic data and equations for calculation of competition between crops and weed populations

Basic data		
Potential daily gross CO_2 assimilation	P_{gs}	$= 300$ kg CH_2O $ha^{-1}d^{-1}$
Development stage	DVS	see Table 72
Specific leaf area	C_f	$= 20\ m^2\ kg^{-1}$
Conversion efficiency for dry matter production	E_g	$= 0.7$
Relative maintenance respiration rate	R_m	$= 0.015\ d^{-1}$
Equations to be used sequentially for each time interval		
Reduction factor for assimilation	RA	$= f(L_t)$
Relative rate of leaf dying	d_s	$= 0.\ d^{-1}$;
for DVS > 1	d_s	$= 0.02\ d^{-1}$
Fraction dry matter for leaf growth	FL	$= f$ (DVS)
Potential gross assimilation rate	PGASS	$= P_{gs}.RA$ kg $ha^{-1}d^{-1}$
Maintenance respiration	MRES	$= TDW.R_m$ kg $ha^{-1}d^{-1}$
Assimilates for increase in dry matter	ASAG	= PGASS − MRES kg $ha^{-1}d^{-1}$
Rate of dry matter increase	DMI	$= ASAG.E_g$ kg $ha^{-1}d^{-1}$
Leaf area index above ½ H_c	$L(H_{hc})$	$= L_c/2 + ((H_w - H_c/2)/H_w) \cdot L_w$ for $H_w > H_c/2$.
Leaf area index above ½ H_w	$L(H_{hw})$	$= L_w/2 + ((H_c - H_w/2)/H_c) - L_c$ for $H_c > H_w/2$.
Rate of dry matter increase of the crop	G_c	$DMI \cdot L_c \cdot e^{-0.65 \cdot L(H_{hc})} / (L_c \cdot e^{-(} \cdot L(H_{hc}) + L_w \cdot e^{-0.65 \cdot L(H_{hw})})$ kg $ha^{-1}d^{-1}$
Rate of dry matter increase of the weeds	G_w	$= DMI - G_c$ kg $ha^{-1}d^{-1}$
Height of the crop	H_c	$= H_c + hi_c\ .\ \Delta t$ if $H_c < h_{mc}$
Death rate of the leaves of the crop	$DWLV_c$	$= q.WLV_c$ kg $ha^{-1}d^{-1}$
Weight of the leaves of the crop	WLV_c	$= WLV_c + (FL.G_c - DWLV_c) \times \Delta t$ kg ha^{-1}
Weight other organs of the crop	WGO_c	$= WGO_c + G_c(1 - FL) \times \Delta t$ kg ha^{-1}
Leaf area index of the crop	L_c	$= WLV_c\ .\ C_f\ .\ 10^{-4}$
Total dry weight of the crop	TDW_w	$= WGO_c + WLV_c$ kg ha^{-1}
Height of the weeds	H_w	$= H_w + hi_w\ .\ \Delta t$ if $H_w < h_{mw}$
Death rate of the leaves of the weeds	$DWLV_w$	$= q.WLV_w$ kg $ha^{-1}d^{-1}$
Weight of the leaves of the weeds	WLV_w	$= WLV_w + (FL.G_w - DWLV_w) \times \Delta t$ kg ha^{-1}
Weight of other organs of the weeds	WGO_w	$= WGO_w + G_w(1 - FL) \times \Delta t$ kg ha
Leaf area index of the weeds	L_w	$= WLV_w\ .\ C_f\ .\ 10^{-4}$
Total dry weight of the weeds	TDW_w	$= WGO_w + WLV_w$ kg ha^{-1}
Total leaf area index	L_t	$= L_w + L_c$

Table 72a. Competition in a 'wheat-like' crop.

	crop	weeds	
Initial height	0.05	0.05	m
Height increase	0.01	0.01	$m\ d^{-1}$
Maximum height	1.0	0.80	m
Initial weight of the leaves	50.0	50.0	$kg\ ha^{-1}$
Initial weight of other organs	50.0	50.0	$kg\ ha^{-1}$

TIME	DVS	RA	FL	PGASS	MRES	ASAG	DMI	LHHC	LHHW	GC	GW	HC	DWLVC
10	0.10	0.18	0.38	54.0	3.0	51.0	35.7	0.12	0.12	17.8	17.8	0.15	0
20	0.20	0.37	0.40	110.5	8.4	102.1	71.5	0.29	0.29	35.7	35.7	0.25	0
30	0.30	0.64	0.43	192.2	19.1	173.1	121.2	0.65	0.65	60.6	60.6	0.35	0
40	0.40	0.87	0.46	260.7	37.3	223.4	156.4	1.29	1.29	78.2	78.2	0.45	0
50	0.50	0.98	0.48	292.7	60.7	232.0	162.4	2.19	2.19	81.2	81.2	0.55	0
60	0.60	1.00	0.48	300.0	85.1	214.9	150.5	3.17	3.17	75.2	75.2	0.65	0
70	0.70	1.00	0.42	300.0	107.6	192.4	134.7	4.06	4.06	67.3	67.3	0.75	0
80	0.80	1.00	0.32	300.0	127.8	172.2	120.5	4.77	4.77	60.3	60.3	0.85	0
90	0.90	1.00	0.21	300.0	145.9	154.1	107.9	5.08	5.40	59.5	48.4	0.95	0
100	1.00	1.00	0.10	300.0	162.1	137.9	96.5	5.01	5.96	63.0	33.5	1.00	0
110	1.20	1.00	0.00	300.0	176.6	123.4	86.4	4.95	6.22	60.5	25.9	1.00	45.7
120	1.50	1.00	0.00	300.0	176.0	124.0	86.8	3.96	4.97	57.7	29.1	1.00	36.6
130	1.80	1.00	0.00	300.0	178.2	121.8	85.3	3.17	3.98	54.1	31.2	1.00	29.2
140	2.00	1.00	0.00	300.0	182.3	117.7	82.4	2.53	3.18	50.2	32.2	1.00	23.4

Table 72a. Competition in a 'wheat-like' crop.

	crop	weeds	
Initial height	0.05	0.05	m
Height increase	0.01	0.01	$m\ d^{-1}$
Maximum height	1.0	0.80	m
Initial weight of the leaves	50.0	50.0	$kg\ ha^{-1}$
Initial weight of other organs	50.0	50.0	$kg\ ha^{-1}$

TIME	WLVC	WGOC	LC	TDWC	HW	DWLVW	WLVW	WGOW	LW	TDWW	LT
10											
20	117	161	0.29	278	0.15	0	117	161	0.29	278	0.58
30	260	376	0.65	636	0.25	0	260	376	0.65	636	1.30
40	518	724	1.29	1242	0.35	0	518	724	1.29	1242	2.59
50	878	1146	2.19	2024	0.45	0	878	1146	2.19	2024	4.39
60	1267	1568	3.17	2835	0.55	0	1267	1568	3.17	2835	6.34
70	1625	1963	4.06	3588	0.65	0	1625	1963	4.06	3588	8.12
80	1907	2354	4.77	4261	0.75	0	1907	2354	4.77	4261	9.54
90	2097	2767	5.24	4864	0.80	0	2097	2767	5.24	4864	10.49
100	2222	3236	5.56	5458	0.80	0	2199	3149	5.50	5348	11.05
110	2285	3803	5.71	6088	0.80	0	2232	3451	5.58	5683	11.29
120	1828	4408	4.57	6236	0.80	44.6	1786	3710	4.46	5496	9.03
130	1462	4985	3.66	6447	0.80	35.7	1429	4001	3.57	5430	7.23
140	1170	5526	2.92	6696	0.80	28.6	1143	4313	2.86	5456	5.78
	936	6029	2.34	6965	0.80	22.9	914	4635	2.29	5549	4.63

Table 72b. Competition in a 'sugar-beet-like' crop.

	crop	weed	
Initial height	0.01	0.05	m
Height increase	0.005	0.01	m d^{-1}
Maximum height	0.3	0.8	m
Initial weight of the leaves	5.0	50.0	kg ha^{-1}
Initial weight of other organs	5.0	50.0	kg ha^{-1}

TIME	DVS	RA	FL	PGASS	MRES	ASAG	DMI	LHHC	LHHW	GC	GW	HC	DWLVC
10	0.10	0.10	0.38	29.7	1.7	28.0	19.6	0.12	0.06	1.7	17.9	0.06	0
20	0.20	0.22	0.40	67.1	4.6	62.5	43.8	0.25	0.15	3.7	40.1	0.11	0
30	0.30	0.44	0.43	133.4	11.2	122.2	85.5	0.57	0.35	6.4	79.1	0.16	0
40	0.40	0.73	0.46	220.2	24.0	196.2	137.3	1.25	0.77	8.21	29.1	0.21	0
50	0.50	0.92	0.48	276.7	44.6	232.1	162.5	2.43	1.51	6.5	156.0	0.26	0
60	0.60	1.00	0.48	300.0	69.0	231.0	161.7	3.89	2.45	3.9	157.9	0.30	0
70	0.70	1.00	0.42	300.0	93.2	206.8	144.7	5.38	3.38	2.0	142.7	0.30	0
80	0.80	1.00	0.32	300.0	114.9	185.1	129.5	6.80	4.13	1.0	128.5	0.30	0
90	0.90	1.00	0.21	300.0	134.4	165.6	115.9	7.73	4.64	0.6	115.3	0.30	0
100	1.00	1.00	0.10	300.0	151.8	148.2	103.8	8.22	4.94	0.5	103.3	0.30	0
110	1.20	1.00	0.00	300.0	167.3	132.7	92.9	8.43	5.07	0.4	92.5	0.30	3.1
120	1.50	1.00	0.00	300.0	168.6	131.4	92.0	6.75	4.06	0.6	91.4	0.30	2.5
130	1.80	1.00	0.00	300.0	172.3	127.7	89.4	5.40	3.25	0.8	88.6	0.30	2.0
140	2.00	1.00	0.00	300.0	177.6	122.4	85.7	4.32	2.60	1.1	84.6	0.30	1.6

Table 72b. Competition in a 'sugar-beet-like' crop.

	crop	weed	
Initial height	0.01	0.05	m
Height increase	0.005	0.01	$m\ d^{-1}$
Maximum height	0.3	0.8	m
Initial weight of the leaves	5.0	50.0	$kg\ ha^{-1}$
Initial weight of other organs	5.0	50.0	$kg\ ha^{-1}$

TIME	WLVC	WGOC	LC	TDWC	HW	DWLVW	WLVW	WGOW	LW	TDWW	LT
10	11	16	0.03	27	0.15	0	118	161	0.29	279	0.32
20	26	38	0.07	64	0.25	0	278	402	0.69	680	0.76
30	53	75	0.13	128	0.35	0	614	857	1.54	1471	1.67
40	91	119	0.23	210	0.45	0	1208	1554	3.02	2762	3.25
50	122	153	0.31	275	0.55	0	1957	2365	4.89	4322	5.20
60	141	173	0.35	314	0.65	0	2707	3194	6.77	5901	7.12
70	149	185	0.37	334	0.75	0	3306	4022	8.27	7328	8.64
80	153	192	0.38	345	0.80	0	3711	4902	9.28	8613	9.66
90	154	197	0.38	351	0.80	0	3953	5813	9.88	9766	10.27
100	155	201	0.39	356	0.80	0	4056	6743	10.14	10799	10.53
110	124	205	0.31	329	0.80	81.1	3246	7667	8.11	10913	8.42
120	99	211	0.25	310	0.80	64.9	2596	8581	6.49	11177	6.74
130	79	220	0.20	299	0.80	51.9	2077	9467	5.19	11544	5.39
140	63	230	0.16	293	0.80	41.5	1661	10313	4.15	11974	4.31

Exercise 86
Calculate the effect of each successive weeding on dry-matter production of the crops in Table 73 and plot the results.
Explain why the dry-matter production of a completely weed-free crop is higher than that of a crop that is weeded several times during its development.

The response of crops and weeds to sub-optimum growing conditions may differ. Crop plants consist, by selection and breeding, of populations with uniform properties, tailored to the needs of mankind. Weeds are plants that are unwanted and a population contains many species that fill the gaps ('niches') not used by the crop. Sub-optimum growing conditions for the crop, such as excess or shortage of water, lack of nutrients, low or extremely high temperatures, favour those species in a weed population that are better adapted to such conditions than the crop itself. So, as a rule, any condition that will interfere with normal crop development not only affects crop production directly, but also increases the risk of crop losses due to weeds. For example, to counteract the effects of weeds in rice cultivation, the crop is, if possible, flooded because the crop is resistant against flooding, but many weeds are not. When flooding fails, an outburst of weed development is the result.

The competition model presented here only demonstrates the principles of competition. Coupling of such models with more elaborate crop growth models can supply more quantitative information, if sufficiently accurate data on growth characteristics of weeds are included. The explanatory value of the competition principle can be tested with data summarized by van Heemst (1985). Table 74 provides facts derived from the literature on the relative yield of a number of crops without weed control and specifies the time, expressed relative to the total crop growth period, that crops should be kept weed free to avoid losses of more than 5%.

Exercise 87
Try to explain differences in crop loss without weed control and in necessary weed-free periods among the crops in Table 74, by applying information given in this section.

Table 73a. Weeding in a 'wheat-like' crop.

	crop	weed	
Initial height	0.05	0.05	m
Height increase	0.01	0.01	$m\ d^{-1}$
Maximum height	1.0	0.80	m
Initial weight of the leaves	50.0	50.0	$kg\ ha^{-1}$
Initial weight of other organs	50.0	50.0	$kg\ ha^{-}$

TIME	DVS	RA	FL	PGASS	MRES	ASAG	DMI	LHHC	LHHW	GC	GW	HC	DWLVC
10	0.10	0.18	0.38	54.0	3.0	51.0	35.7	0.12	0.12	17.8	17.8	0.15	0
20	0.20	0.37	0.40	110.5	8.4	102.1	71.5	0.29	0.29	35.7	35.7	0.25	0
30	0.30	0.64	0.43	192.2	19.1	173.1	121.2	0.65	0.65	60.6	60.6	0.35	0
40	0.40	0.68	0.46	203.2	20.5	182.7	127.9	0.65	1.29	120.0	7.9	0.45	0
50	0.50	0.90	0.48	269.8	39.7	230.2	161.1	1.34	2.38	154.7	6.4	0.55	0
60	0.60	0.99	0.48	297.9	63.8	234.1	163.9	2.27	3.71	159.8	4.1	0.65	0
70	0.70	1.00	0.42	300.0	88.4	211.6	148.1	3.22	4.94	145.5	2.6	0.75	0
80	0.80	1.00	0.32	300.0	110.6	189.4	132.6	4.03	5.84	130.7	1.9	0.85	0
90	0.90	1.00	0.21	300.0	130.5	169.5	118.6	4.57	6.35	117.0	1.6	0.95	0
100	1.00	1.00	0.10	300.0	148.3	151.7	106.2	4.90	6.59	104.7	1.4	1.00	0
110	1.20	1.00	0.00	300.0	164.2	135.8	95.0	5.06	6.44	93.5	1.5	1.00	78.9
120	1.50	1.00	0.00	300.0	166.2	133.8	93.7	4.06	4.89	91.5	2.2	1.00	63.1
130	1.80	1.00	0.00	300.0	170.4	129.6	90.7	3.25	3.91	88.4	2.3	1.00	50.5
140	2.00	1.00	0.00	300.0	176.1	123.9	86.7	2.60	3.13	84.3	2.4	1.00	40.4

Table 73a.(continued)

TIME	WLVC	WGOC	LC	TDWC	HW	DWLVW	WLVW	WGOW	LW	TDWW	LT
10	117	161	0.29	278	0.15	0	117	161	0.29	278	0.59
20	260	376	0.65	636	0.25	0	260	376	0.65	636	1.30
30	518	724	1.29	1242	0.04	0	52	72	0.13	124	1.42
40	1070	1372	2.67	2442	0.14	0	88	115	0.22	203	2.89
50	1812	2176	4.53	3988	0.24	0	119	148	0.30	267	4.83
60	2571	3015	6.43	5586	0.34	0	138	170	0.35	308	6.77
70	3182	3859	7.96	7041	0.44	0	149	185	0.37	334	8.33
80	3594	4754	8.98	8348	0.54	0	155	198	0.39	353	9.37
90	3840	5679	9.60	9519	0.64	0	158	210	0.40	369	10.00
100	3945	6621	9.86	10566	0.74	0	160	223	0.40	383	10.26
110	3156	7556	7.89	10712	0.80	3.2	128	239	0.32	367	8.21
120	2524	8471	6.31	10966	0.80	2.6	102	260	0.26	363	6.57
130	2020	9355	5.05	11375	0.80	2.0	82	284	0.20	366	5.25
140	1616	10198	4.04	11814	0.80	1.6	66	308	0.16	373	4.20

Table 73b. Weeding in a 'sugar-beet-like' crop.

	crop	weed	
Initial height	0.01	0.05	m
Height increase	0.005	0.01	$m\ d^{-1}$
Maximum height	0.3	0.8	m
Initial weight of the leaves	5.0	50.0	$kg\ ha^{-1}$
Initial weight of other organs	5.0	50.0	$kg\ ha^{-1}$

TIME	DVS	RA	FL	PGASS	MRES	ASAG	DMI	LHHC	LHHW	GC	GW	HC	DWLVC
10	0.10	0.10	0.38	29.7	1.7	28.0	19.6	0.12	0.06	1.7	17.9	0.06	0
20	0.20	0.22	0.40	67.1	4.6	62.5	43.8	0.25	0.15	3.7	40.1	0.11	0
30	0.30	0.44	0.43	133.4	11.2	122.2	85.5	0.57	0.35	6.4	79.1	0.16	0
40	0.40	0.20	0.46	60.7	4.1	56.6	39.6	0.07	0.20	19.3	20.3	0.21	0
50	0.50	0.44	0.48	131.1	10.1	121.0	84.7	0.26	0.44	42.9	41.8	0.26	0
60	0.60	0.53	0.48	159.6	12.4	147.2	103.1	0.44	0.88	95.7	7.4	0.30	0
70	0.70	0.82	0.42	246.6	27.9	218.7	153.1	1.00	1.68	144.9	8.2	0.30	0
80	0.80	0.95	0.32	284.8	50.8	234.0	163.8	1.85	2.35	155.4	8.4	0.30	0
90	0.90	1.00	0.21	300.0	75.4	224.6	157.2	2.55	2.35	145.8	11.4	0.30	0
100	1.00	1.00	0.10	300.0	99.0	201.0	140.7	3.01	1.82	122.1	18.6	0.30	0
110	1.20	1.00	0.00	300.0	120.1	179.9	125.9	3.22	0.96	95.0	30.9	0.30	46.6
120	1.50	1.00	0.00	300.0	131.5	168.5	118.0	2.59	0.17	86.8	31.2	0.30	37.3
130	1.80	0.96	0.00	288.1	143.2	144.9	101.4	2.08	0.14	80.2	21.2	0.30	29.8
140	2.00	0.92	0.00	276.1	153.6	122.5	85.7	1.67	0.11	71.1	14.6	0.30	23.9

Table 73b.(continued)

TIME	WLVC	WGOC	LC	TDWC	HW	DWLVW	WLVW	WGOW	LW	TDWW	LT
10	12	15	0.03	27	0.15	0	118	161	0.29	279	0.32
20	26	38	0.07	64	0.25	0	278	402	0.69	680	0.76
30	54	74	0.13	128	0.04	0	61	86	0.15	147	0.29
40	142	179	0.36	321	0.14	0	155	195	0.39	350	0.74
50	348	402	0.87	750	0.02	0	36	41	0.09	77	0.96
60	803	905	2.01	1708	0.12	0	70	80	0.18	150	2.18
70	1412	1745	3.53	3157	0.22	0	105	127	0.26	232	3.79
80	1901	2810	4.75	4711	0.32	0	131	185	0.33	316	5.08
90	2207	3962	5.52	6169	0.42	0	155	275	0.39	430	5.91
100	2330	5060	5.82	7390	0.52	0	174	443	0.43	617	6.26
110	1864	6011	4.66	7875	0.62	3.5	139	751	0.35	890	5.01
120	1491	6879	3.73	8370	0.72	2.8	111	1063	0.28	1174	4.01
130	1193	7681	2.98	8874	0.80	2.2	89	1275	0.22	1364	3.20
140	954	8392	2.39	9346	0.80	1.8	71	1422	0.18	1493	2.56

Table 74. Estimated end of critical period relative to total crop growth period and yield without weed control relative to yield with complete weed control for a number of agricultural crops [a].

Crop	Estimated relative end of critical period	Estimated relative yield without weed control
wheat	0.19	0.75
peas	0.21	0.70
potato	0.22	0.68
sorghum	0.26	0.61
cabbage	0.27	0.59
maize	0.27	0.59
soya bean	0.27	0.58
sweet potato	0.29	0.54
transplanted rice	0.30	0.52
sugar-cane	0.33	0.47
flax	0.35	0.42
groundnut	0.36	0.41
beans	0.36	0.41
red beet	0.36	0.40
tobacco	0.39	0.34
okra	0.41	0.31
sugar-beet	0.43	0.26
upland rice	0.44	0.25
yam	0.47	0.19
cassava	0.47	0.18
cotton	0.49	0.14
garlic	0.50	0.12
mungbean	0.56	0.00
carrots	0.56	0.00
onions	0.56	0.00

[a] Other crop-specific agricultural operations as earthing up (potato, sugar-cane), thinning (cotton, sugar-beet), transplanting (tobacco, rice) are included in determining the yield without weed control, although these treatments have effects on weed competition.

6.3.4 Pests and diseases

The effects of pests and diseases on crop yields vary strongly among crops and yield levels. The number of different pests and diseases is so large that a general treatment of the effects of pests and diseases is almost impossible. However, in agricultural practice the number of relevant pests and diseases at one site or in a region is limited. Because the aim is not an exhaustive description of the effects of all possible pests and diseases on crops, the causal agents are classified according to their mode of action on the crop and the susceptibility of the crop to each of these groups is defined. Adopting this approach may result in a methodology that can be used for a simple evaluation of potential and actual crop losses in relation to environment and farming practice.

Pests and diseases may be classified according to population development and according to the way in which they interact with the productivity of the crop. In the first classification, a distinction can be made between 'single interest' and 'multiple interest' pests and diseases. Single interest (monocyclic) pests and diseases are characterized by one infection cycle during the growing period of the crop. For this group of causal agents, the expected damage level depends mainly on the initial level of attack, for example seed and seedling removal by pests and diseases during a very limited period in crop development. Smuts and bunts of cereals and some one-generation insect pests belong to this group. Multiple interest (polycyclic) pests and diseases are characterized by the occurrence of more than one generation during the growing season. The damage level depends not only on the initial level of infection, but also on the ability of the causal agent to develop through repetitive life cycles to a level that affects crop production. Since the development of such pests and diseases depends, at least partly, on the crop characteristics and the course of crop development, the effects of such pests and diseases may vary considerably with production level. Important pests and diseases belonging to this group are cereal aphids, leaf blight, leaf spot diseases, rusts and mildews.

Another criterion for classifying pests and diseases is the mode of interaction with the host. Certain pests and diseases remove green tissue or whole plants without affecting the remaining plant parts or plants, except through canopy density. Examples of these are cereal leaf beetles and various soil pests that remove whole seedlings. Many other pests and diseases not only affect the infested tissue but also influence the physiology of plant parts not yet infested, for example through effects on photosynthesis and leaf ageing, such as caused by cereal aphids and many leaf diseases. Detailed evaluation of the effects of this type of infestation is only possible by taking into account crop physiology and population growth of the causal agent concurrently. Examples of such an approach are given by Rabbinge & Rijsdijk (1982). In this section, the emphasis is on a methodology for evaluating effects of polycyclic pests and diseases on crops at different production levels.

6.3.5 Dynamics of polycyclic population growth

In principle, population growth of a polycyclic organism follows an exponential pattern. The growth rate of that population is, according to differential calculus:

$$\frac{dP}{dt} = r \cdot P \qquad (107)$$

After integration the time course of the population is described by:

$$P_t = P_0 \cdot e^{rt} \tag{108}$$

where

P_0 is the initial level of the population
t is time (d)
r is the relative growth rate (d^{-1})

As the population cannot expand infinitely, a maximum level of the population or a carrying capacity has to be defined. The actual growth rate of the population is influenced by this maximum level, not only at the moment the maximum level P_m is reached, but long before. This may be taken into account if it is assumed that the growth rate of the population is proportional to the fraction of the host that is not yet infected. This inhibition mechanism is explained by non-effective double infections in the case of fungi and by intra-specific inhibition mechanisms in insect populations. The rate of growth of the population is then:

$$\frac{dP}{dt} = r \cdot P \cdot (1 - P/P_m) \tag{109}$$

The population size at time t follows from integration of Equation 109:

$$P_t = \frac{P_m}{1 + K \cdot e^{-rt}} \; ; \; K = \frac{P_m - P_0}{P_0} \tag{110}$$

Such a population growth model is called a logistic model. The logistic growth model describes population growth for insects and pathogenic fungi only approximately, because in reality delays occur such as latent periods for fungi and non-reproductive periods as larvae and pupae stages in insect populations. These delays are not explicitely defined in the equations. Introducing those delays, too, leads to numerical models of a more complex nature. Detailed information on crop, environment and pests and diseases is necessary for such models. Nevertheless, logistic models may be used in evaluating effects of pests and diseases on productivity. For that purpose the relative growth rate, r, of the population should be defined not as a constant throughout the growing cycle, but as a function of a crop characteristic such as development stage, which reflects both crop physiology and past environmental conditions, and the resistance of the host. The calculation of the population dynamics should be carried out for sufficiently small time intervals to take account of the effects of changes in its parameter values. The values for the parameters r and P_m as a function of crop development can be obtained from more complex models or from experiments where pest or disease levels are recorded sequentially in combination with crop characteristics.

Exercise 88

Calculate the r values during crop development from disease readings and crop characteristics as given in Table 75. Calculate the growth rate of the population at the time of disease readings.

Coupling of calculations on pathogen population development and its consequences for crop production with calculations of crop production itself will be demonstrated for a cereal rust on wheat. The calculation procedure used in Section 3.4 for Production Situation 2 will be used with some simplification in parameters to avoid excessive use of calculus. The complete calculation procedure is summarized in Table 76. The epidemic of cereal rust takes place by colonization of the leaf tissue by the fungus. The level of infection is expressed in kilograms of living infected leaves per hectare.

In the model the amount of infected leaf tissue is thus calculated as a separate state variable, Y_i. The rate of change of this variable is:

$$\frac{dY_i}{dt} = r \cdot Y_i \cdot (1 - Y_i/Y_m) - Y_d \tag{111}$$

where

Y_m is the total weight of living leaf tissue (kg ha^{-1})
r is the relative growth rate of the fungus population as a function of the development stage of the crop (see Table 77) (d^{-1})
Y_d is the death rate of the diseased leaf tissue (kg ha^{-1} d^{-1})

Table 75. Disease readings and crop development of an epidemic of yellow rust on wheat.

Time	DVS	Severity (P_i/P_m)
40	0.1	0.00001
70	0.3	0.0002
90	0.5	0.005
110	0.8	0.08
125	1.0	0.2
135	1.3	0.5

Table 76. Parameters and equations for the combined crop-disease model

Potential daily gross CO_2 assimilation	P_{gs}	= 300 kg CH_2O/ha
Development stage of the crop	DVS	= f (TIME)
Specific leaf area	SLA	= 25 $m^2 kg^{-1}$
Potential evapotranspiration	ETO	= f (TIME)
Total water supply	IM	= f (TIME)
Soil water depletion factor	P	= f (Tm) see Table 20
Soil moisture content of air dry soil	SMa	= 0.03
Soil moisture content at fieldcapacity	SMfc	= 0.225
Soil moisture content at wilting point	SMw	= 0.09
Potential rooting depth	Drm	= 1500 m
Growth rate of the roots	Rr	= 100 mm/decade
Conversion efficiency for dry matter production	Eg	= 0.7
Relative rate of disease senescence	Qd	= .025
Relative maintenance respiration rate	Rm	= 0.015 day^{-1}
Ratio between dying of diseased and healthy leaves	Fd	= 3.
Equations to be calculated sequentially for each time interval		
1. Reduction factor for assimilation	RA	= f(L) see Table 11
2. Proportionality factor for disease severity	Fs	= f(PROPD)
3. Relative rate of leaf senescence	Ds	= 0.0; for DVS > 1 Ds = 0.02/day
4. Fraction dry matter for leaf growth	FL	= f(DVS) see Table 12
5. Fraction dry matter for root growth	FR	= f(DVS) see Table 12
6. Fraction dry matter for stem growth	FS	= f(DVS) see Table 12
7. Fraction dry matter for grain growth	FG	= f(DVS) see Table 12
8. Potential gross assimilation	PGASS	= Pgs.RA.Δt kg/ha
9. Maximum evaporation from soil surface	Em	= ETo.(1 – RA) mm/decade
10. Maximum transpiration	Tm	= ETo.RA mm/decade
11. Actual evaporation	Ea	= Em.(SMr – SMa)/(SMfc – SMa) mm/decad
12. Critical soil moisture content	SMcr	= (1 – P).(SMfc – SMw) + SMw
13. Actual transpiration	T	= Tm; for SMcr > SMr
	T	Tm.(SMr – SMw)/(SMcr – SMw)
14. Rooting depth	RD	= RD + Rr, for RD < Drm
15. Moisture added to rooted zone by root growth	dMr	= Wnr.Rr/(Drm – RD) mm/decade
16. Change of moisture in rooted part of the soil	DWr	= IM + dMr – Ea – T mm/decade
17. Soil moisture in rooted zone	Wr	= Wr + Dwr.Δt mm
18. Soil moisture content of rooted zone	SMr	= Wr/RD
19. Amount of moisture in non-rooted zone	Wnr	= Wnr – dMr.Δt mm
20. Actual gross assimilation	GASS	= PGASS.T/Tm kg/ha
21. Maintenance respiration	MRES	= TDW.Rm.Δt kg/ha
22. Assimilation for increase of dry matter	ASAG	= GASS – MRES kg/ha
23. Total relative rate of dying of leaves	Q	= (Dw.(1 – T/Tm) + Ds) . Fs ; for Q < Qd.PROPD Q = Qd.PROPD
24. Dry matter increase	DMI	= ASAG . Eg . (1 – PROPD . (1 – RA)) kg/ha
25. Death rate of the leaves of the crop	DWLV	= WLV . Q . Δt kg/ha
26. Weight of the leaves of the crop	WLV	= WLV + FL.DMI – DWLV kg/ha
27. Leaf area index of the crop	L	= WLV . SLA . 0.0001; for DVS > L ⩾ 0.5
28. Weight of the roots	WRT	= WRT + DMI.FR kg/ha
29. Weight of the stems	WST	= WST + DMI.FS kg/ha
30. Weight of the grains	WGR	= WGR + DMI.FG kg/ha
31. Total dry weight	TDW	= WLV + WGR + WST + WRT kg/ha
32. Total dry weight of dead leaves	TDWD	= TDWD + DWLV kg/ha
33. Death rate of diseased leaves	Yd	= Fd.Q.WLV.Y.Δt/((Fd – 1).Y + WLV)
34. Relative growth rate of the disease	r	= f(DVS) see Table 77
35. Weight of diseased leaves	Y	= WLV/(1 + (WLV – Y)/Y. EXP(– r.Δt)) for Y < WLV
36. Disease severity	PROPD	= Y/WLV

Table 77. Parameter values for development of an early and a late disease on wheat.

TIME	DVS	'early' r(rust)	'late' r(leafspot)	Y_i/Y_m	F_{ds}
0	0.01	0.11	0.04	0.0	1.0
	0.1			0.1	1.0
	0.2			0.2	1.5
	0.3			0.3	2.0
	0.4			0.5	2.0
	0.5		0.09	1.0	1.0
	0.6				
	0.7				
	0.8				
	0.9				
100	1.0	0.13	0.15		
	1.2	0.05			
	1.5	0.0			
140	2.0	0.0	0.15		

Diseased leaves die, either from senescence or as a result of the disease. The death rate of diseased leaves is not proportional to the total death rate of leaves, since normally the disease is not homogeneously distributed within the canopy. Epidemics take time to develop; fructifications that can cause new infections appear only after a certain latent period, so older leaves, low in the canopy, have a much higher chance to be infected than young leaves. As old leaves die first, it is assumed that diseased leaves die with a relative death rate that is a factor F_d higher than healthy leaves. If the overall relative death rate of all leaf tissue (Section 3.4) equals q_t, the relative death rate of the diseased leaves, q_i, is calculated as:

$$q_t \cdot Y_m = q_i \cdot Y_i + q_i/F_d \cdot (Y_m - Y_i) \quad (112)$$

which, after some rearrangement yields:

$$q_i = F_d \cdot q_t \cdot Y_m/((F_d - 1) \cdot Y_i + Y_m) \quad (113)$$

The death rate of the infected leaves is thus equal to:

$$Y_d = F_d \cdot q_t \cdot Y_m/((F_d - 1) \cdot Y_i + Y_m) \cdot Y_i \quad (114)$$

Dying of non – infected leaf tissue may be caused by stress through lack of water or from senescence. However, disease may also cause death of non – infected leaves,for example enclosures of healthy leaf tissue within infected leaves. When the infestation is relatively mild, the relative death rate of leaves is assumed to be proportional to the level of infestation. When the infection increases, still – healthy leaf tissue in the surroundings of the disease lesions starts to die. The relation between disease severity and death of healthy leaves is characteristic for the host – pathogen combination. A rough estimate of this effect for cereal rusts is given in Table 77. Now q_t is defined as:

$$q_t = (d_w \cdot (1 - T/T_m) + d_s) \cdot F_{ds} \qquad (115)$$

$$F_{ds} = f(Y_i/Y_m)$$

where d_w and d_s are the maximum relative death rate caused by water stress and senescence, respectively, and F_{ds} the proportionality factor for the disease severity.

Finally, the effect of ageing of the pathogen itself should be taken into account. Disappearance of the disease by ageing proceeds at a more or less constant relative rate that is specific for a pathogen – host combination. For cereal rusts it is between 0.05 and 0.01 per day. It is assumed that if this value is smaller than q_t, all dying infected leaf tissue is taken into account in the previous definition. If this value q_d is higher, it will replace q_t.

The effect of the epidemic on crop production is incorporated as follows. Infected leaf tissue is assumed to take part in assimilation and respiration. The assimilates produced are, however, not available for crop growth but are used for growth and maintenance of the fungus, while the maintenance respiration continues as in healthy leaves. The decline in production due to the disease is proportional to the amount of diseased leaf tissue. As discussed earlier, the disease is not evenly distributed within the canopy. This implies that the effect of the disease will be relatively small in crops with a leaf area index of 4 or more, because most of the radiation is intercepted by the healthy leaves at the top of the canopy, and the infected leaves at the bottom contribute very little to assimilation. This effect can be quantified.

First, the distribution of the disease in the canopy will be treated. For that purpose the crop canopy is divided in an upper and a lower half, each with 0.5 LAI. When the proportion of the diseased leaves is close to zero, all the disease will be concentrated in the lower half of the canopy and it will be absent in the upper half. When all leaves in the canopy are infected, e.g. the proportion of diseased leaves equals one, the disease is evenly distributed over the canopy.

The fraction of disease in the lower half of the canopy is:

$$d_l = 1/(1 + P_d) \qquad (116)$$

The fraction of disease in the upper half of the canopy is:

$$d_u = P_d/(1 + P_d) \qquad (117)$$

where

$$P_d = Y_i/Y_m$$

The effect of the disease on the dry-matter production of the crop depends on the radiation intercepted by diseased leaves. As demonstrated above, the disease is unevenly distributed over the canopy. The fraction of the radiation intercepted in the upper half of the canopy is:

$$1 - e^{-k_e \,.\, LAI/2} \tag{118}$$

The fraction of radiation intercepted in the lower half of the canopy is:

$$e^{-k_e \,.\, LAI/2} - e^{-k_e \,.\, LAI} \tag{119}$$

The proportions of the total radiation intercepted in the upper and the lower halves of the canopy are respectively:

$$P_u = \frac{1 - e^{-k_e \,.\, LAI/2}}{1 - e^{-k_e \,.\, LAI}} \tag{120}$$

$$P_l = \frac{e^{-k_e \,.\, LAI/2} - e^{-k_e \,.\, LAI}}{1 - e^{-k_e \,.\, LAI}} \tag{121}$$

The dry matter increase due to interception of radiation in the upper half of the canopy, corrected for the effect of disease, can now be defined as:

$$DMI_u = ASAG \cdot E_g \cdot P_u \cdot (1 - d_u \cdot 2 \cdot P_d) \tag{122}$$

and the dry matter increase due to interception of radiation in the lower half of the canopy as:

$$DMI_l = ASAG \cdot E_g \cdot P_l \cdot (1 - d_l \cdot 2 \cdot P_d) \tag{123}$$

so

$$DMI = DMI_u + DMI_l \tag{124}$$

Exercise 89

Make a plot of the effect of disease on dry-matter production for values of Y_i/Y_m equal to 0.1, 0.3, 0.5, 0.7, and 0.9 for LAI values of 1, 3, 5, and 7. Assume a value of 0.65 for k_e.

A further adjustment has to be made because in comparison to the original model of Section 3.4, this disease only affects leaf blades and sometimes leaf sheaths. However, the heads and stems that are not affected, contribute to assimilation, even if all leaves are dead. Therefore, a minimum value for LAI after anthesis of 0.5 is maintained. On the basis of these assumptions it is possible to calculate crop production and the effect of the epidemic in combination. Table 76 gives the calculation procedure summarized in a FORTRAN programme. The results are given in Table 78.

The disease treated in this example develops mostly during leaf development before anthesis. After anthesis, its development slows down quickly and midway between anthesis and maturity it comes to a complete stop. Other diseases — Septoria leafspot, for instance — develop slowly during leaf formation, but with increasing temperature they continue to develop until crop maturation. The effect of such a 'late' disease can be calculated using a relative growth rate, r, of the fungus as given in Table 77. The impact of both disease types on crop production in a situation with optimum and sub-optimum water supply is presented in Table 79, which gives the final grain yields. The more severe impact of the 'early' disease can be explained by the fact that it affects the maximum leaf area index, which has an effect on the whole post-anthesis period while the late disease only accelerates leaf death after leaf formation is completed.

6.3.6 Interaction of nutrient status with pests and diseases.

When nutrients limit crop growth, the impact of diseases and pests on crop production may be different from that in the optimum growth situation. For example, when N supply is the limiting factor, the yield estimate is adapted for the amount of N available. The dynamics of N in the crop are, however, not considered. If N supply to the crop is limiting, redistribution of N takes place from vegetative organs to the grains. That process accelerates leaf senescence and causes increased leaf death, partly explaining the lower yield that is obtained under N limiting conditions, as the leaf area index decreases more rapidly and assimilation will be considerably lower. As the leaves are the substrate upon which leaf diseases and many pests rely, interaction is to be expected. The effect of limiting N supply can be expressed in the relative death rate of leaves, which governs the leaf area duration, i.e. the integrated value of leaf area index. Table 79 summarizes the results obtained from the calculation procedure illustrated in Table 76, including the effect of non-optimum N supply expressed as an increase in d_s, for two disease patterns and limited availability of water.

The proportion of loss caused by a disease or pest depends, therefore, also on the impact of other growth limiting factors. It demonstrates why crops with a potentially high production level may suffer more than proportionally from a certain infestation of a pest or disease than crops with a lower produc-

Table 78. Effect of an 'early disease' on crop growth using the programme from Table 76.

Without disease					With disease					
TIME	WLV	LAI	WGR	TDW	WLV	LAI	WGR	TDW	Y_i	P_d
0	50	0.100	0	100	50	0.100	0	100	0.200	0.004
10	133	0.266	0	243	133	0.266	0	243	0.423	0.003
20	221	0.443	0	384	221	0.443	0	384	0.771	0.003
30	283	0.566	0	506	282	0.566	0	505	1.345	0.005
40	619	1.238	0	1155	617	1.235	0	1152	2.872	0.005
50	1099	2.198	0	2283	1095	2.190	0	2275	6.179	0.006
60	1436	2.872	0	3382	1430	2.861	0	3368	12.748	0.009
70	1830	3.662	0	5098	1823	3.646	0	5074	28.406	0.016
80	2033	4.067	0	6786	2024	4.048	0	6749	63.629	0.031
90	2127	4.255	781	8349	2116	4.233	771	8292	142.501	0.067
100	1701	3.404	2528	9671	1693	3.387	2465	9563	239.926	0.142
110	1361	2.723	4006	10808	1284	2.568	3820	10508	207.340	0.161
120	1089	2.178	5194	11724	948	1.897	4854	11207	84.400	0.089
130	871	1.743	6084	12396	758	1.517	5607	11770	41.412	0.055
140	697	1.394	6680	12818	606	1.214	6104	12116	19.011	0.301

Table 79. Calculated grain yields of a crop with an 'early' disease, with a 'late' disease, and without disease, for wet and dry conditions, and for optimum and suboptimum nitrogen conditions.

N supply	Disease	Dry	Wet
Optimum	'early'	3435	6105
	'late'	3521	6123
	'no disease'	4026	6680
Suboptimum	'early'	2204	4345
	'late'	2221	4600
	'no disease'	2375	4700

tion capacity, especially when the pest or disease develops mainly after completion of leaf formation.

6.3.7 *Effects of weather*

Effects of weather conditions on the development of pests and diseases is treated in an indirect way using the relation between the relative growth rate of the pest or disease and the development stage of the crop. As crop and pest or disease do not always react in a similar fashion to different weather conditions, such relations are probably weather-specific. Because it is impossible to establish experimentally the relation between the relative growth rate of the causal agent and the development stage of the crop for each weather type, it is advisable to assess effects of differences in weather conditions on population growth separately. This can be done by using more fundamental models for population growth of pests and diseases applied to various weather conditions (Rijsdijk & Zadoks, 1979).

6.3.8 *Other effects on population growth*

Other effects on population development of pests and diseases, such as the direct effect of the nitrogen status of the canopy on the growth rate of the population, are not treated here. There is evidence that at least some important pests and diseases that rely on living tissue, develop more rapidly on crops optimally supplied with N than on crops with a sub-optimal supply of N (Rabbinge et al., 1981, Rijsdijk, 1980; Darwinkel, 1980a, 1980b). The reverse may be true for fungi that use dead leaf tissue for fructification. However, information about these effects should again be assessed using more complex models. The results of such studies may be included in the simpler approach by redefining the parameter values.

6.3.9 Control of weeds, pests and diseases

Control of weeds, pests and diseases is advisable in many situations. Control measures can be classified in preventive measures, such as growing resistant varieties, using crop rotation schemes in which the causal agents are, at least partly, controlled by reducing their population in fallow periods, flooding of the land, etc., and direct control measures. Direct control measures are mainly weeding and application of herbicides against weeds, and the use of pesticides against pests and diseases. In some cases sophisticated techniques of biological control may be applied. These control measures rely heavily on available resources of labour, cash and management. The capital is invested in spraying equipment and the sprayed product; and management refers to the ability of the farmer to use the resources as efficiently as possible. The labour requirement for weed control differs markedly between subsistence farming and high-input farming in the Western world. Manual weeding of a crop demands 50-150 times more labour than the application of herbicides with advanced spraying equipment. This heavy labour demand limits the area of a crop that can be tended. In agricultural practice, generally, control of weeds seems to prevail over control of pest and diseases. One reason may be that control of pests and diseases is expensive, so that it is only worthwile in a more or less weed-free crop. Another reason is the fact that no capital is needed for manual weeding. Even in the most primitive agricultural system, weeds can be removed by hand or with a simple implement, while for control of pests and diseases relatively expensive chemicals and at least some spraying equipment – however simple – is needed.

When chemicals are used, a problem is that their application in most instances does not lead to complete control. The reasons for such incomplete control may be a limited effectiviness of the chemical control to each specific weed, pest or disease, an improperly timed application, unfavourable weather conditions, etc. The ability of the farmer to judge the necessity for application of the appropriate chemicals at the proper time depends on the management skill. In this respect, local expertise, an effective extension service, and the education level of the farmer are of great importance. Even under intensive management, control measures are seldom completely effective due to only partial control of the causal agent.

It is clear that the expected loss through weeds, pests and diseases cannot be the only criterion for estimating whether control measures are economically attractive. An approach is necessary that takes into account differences in efficiency of control as related to management level. The essential question is not the magnitude of loss caused by a certain weed, pest or disease but the yield increment that can be gained by control measures. Even under a high management level, control measures are seldom fully effective because of only partial control of the causal agents. An approach to answer that question, taking into account different management levels, is illustrated in Figure 70. It shows a frequency distribution of the effect of one application of a mixture of broad-spectrum fungicides against 'ripening diseases' on grain yield of winter wheat in the Netherlands. Some five diseases may be involved. The fungicide mixture was applied at the beginning of anthesis, irrespective of the intensity of symptoms of the diseases (Rijsdijk, 1979). The mean costs of the treatment, expressed in kilograms grain per hectare, was slightly higher than the mean of the effect; the median of the effect was even lower. Clearly, on average, the cost of the treatment is higher than the benefits, so a routine application is not profitable. A closer examination of the observations on which Figure 70 is based showed considerable differences in disease incidence among fields and among years. If disease incidence had been used as a criterion for fungicide application, many fields would not have been treated, while other fields would have been treated much earlier in the season, to avoid disease levels that would damage the crop irreversibly before the fungicide was applied. This would have significantly increased the cost – effectiviness of the treatments. A routine treatment with a fixed mixture of chemicals at a time fixed by date or development stage of the crop requires very little of the management abilities of the farmer. The only condition is that the standard application must pay in the long run. The mean expected gain of the treatment should be clearly higher than the mean expected costs of the treatment. If the management level is higher, the effectiveness of chemical control can be increased by careful inspection of the crop and adaptation of the chemicals to specific weeds, pests or diseases.

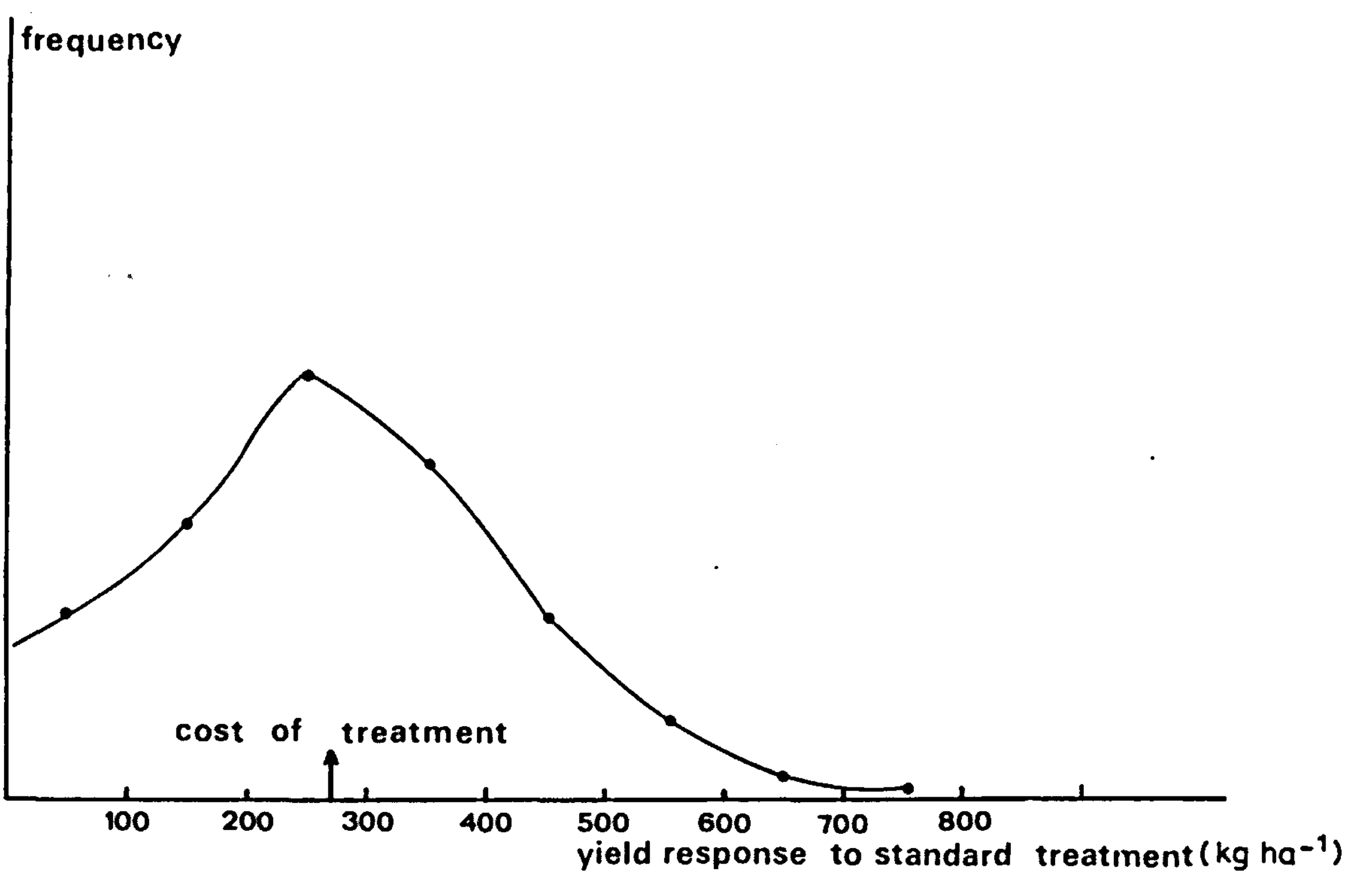

Figure 70. The frequency distribution of yield response to standard treatment with biocides.

Exercise 90

Explain why in a situation of sophisticated management, chemical treatment may be profitable, even if the value of the mean yield increase over the years is less than the mean costs of a treatment.

Considering the effects of the production situation on losses due to weeds, pests and diseases and the prospects of reducing these losses, a hypothesis for their control may be summarized as below.

Production Situation 1:
Production determined by radiation and temperature only.
Chemical control of weeds, pests and diseases. A high effectiviness of biocide application because of sophisticated management.

Production situation 2:
Water supply limiting at times.
Chemical control of weeds, pests and diseases. Effectiviness of biocide application is less due to 'natural' variations in yield. Management form is sophisticated to reasonable.

Productions Situation 3:
Water and nutrients limiting at times.
Chemical and/or manual weed control. Low control of pests and diseases. Relatively low level of management.

Production Situation 4:
Low input farming.
Some manual weeding, no control of pests and diseases.

More specific conclusions for specific situations can,however, only be obtained by defining all the parameters involved and eventually using optimization techniques to find the most profitable combination of input factors for each production situation.