REVIEW OF QUANTITATIVE ROOT LENGTH DATA IN AGRICULTURE

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ABSTRACT

Quantitative data on specific root length (length/dry weight ratio) and root length density in different layers of the soil are summarized from literature for various crops.

INTRODUCTION

In the past two decades, as root research became more oriented to analysis of transport problems, root length and root surface area have replaced root dry weight as the root parameter of primary interest. Considerable effort has been spent on quantifying root length densities of various crops and other plants under various soil conditions. Research has shown that considerable variation in root length densities (cm root length per cm^3 soil volume) exists. Specific root lengths (m of root length per g of root dry weight), however, is reasonably constant within a species or cultivar and average values can be used in first approximation to convert older root weight data into root length densities. As model calculations of nutrient uptake based on root length data get wider applicability, the need for estimates from literature, however rough, increases. Quantitative data were summarized earlier by Nye and Tinker (1977). The present survey does not claim to be complete, but it may form a starting point for a more extensive review in the future.

Frequently one finds in the literature estimates of root length based on root dry weight and average root diameter. Such estimates are unreliable because a number of complicating factors are neglected. As shown by Van Noordwijk (1987), the ratio of total length and dry weight of a set of cylinders can be formulated as:

$$L_r/Y_{D,r} = 1/(\pi . M_{d,r} (1-\epsilon_r) S_r \overline{R}_o^2$$

$$\text{with } \overline{R}_o^2 = \text{var}(R_o) + \overline{R}_o^2$$

L_r = root length [m]
$Y_{D,r}$ = root dry weight [g]
$M_{d,r}$ = dry matter content as a fraction of fresh weight -]

ϵ_r - air-filled root porosity as a fraction of root volume [

S_r - specific weight of non-air-filled root tissue [mg/mm³]

$\tilde{R}_o$ - quadratic average root radius [mm]

$\bar{R}_o$ - (linear) average root radius [mm]

If the variance in root radius is neglected and the linear average root radius is used instead, estimates can easily be wrong by a factor of 2.

In the present review we have only used references reporting both root dry weight and root length data and references giving root length density data. Crops have been arranged according to the standard taxonomic classification system. In Figure 1 the specific root length data are summarized, indicating the range of values for each crop reported in a reference and the average value. Details can be found in the table. According to this summary 200 m/g is a reasonable first estimate for most cereals, and around 400 m/g for other grasses. For dicotyledonous crops a range of 100-400 m/g covers most of the present data.

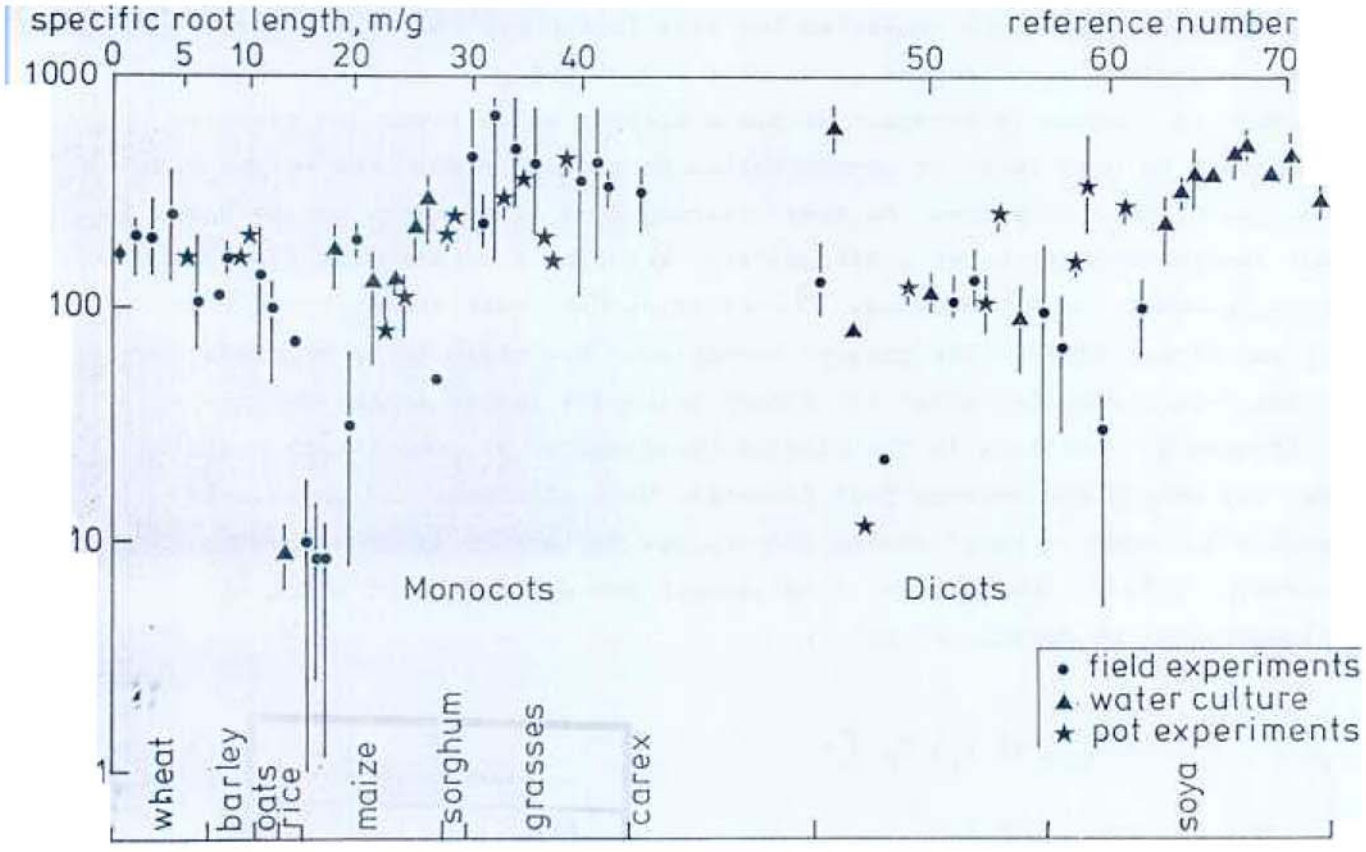

Fig. 1. Summary of literature data on specific root length; plant species have been arranged in taxonomic order; details can be found in table 1.

In the table the following entries are given: reference (abbreviated), crop and cultivar, age at sampling or growth stage, method of root sampling, depth of sampling, principal source of variation studied, number in figure 1 if specific root length data are given, average value of specific root length $L_r/Y_{r,D}$, average root diameter $2R_o$, total root length per unit cropped surface area L_{ra}, root length density L_{rv}: averaged over rooted zone (I) and for three separate zones: 0-0.3 (II), 0.3-0.6 (III) and 0.6-0.9 m (IV).

The authors welcome any published or unpublished data to update the present review.

TABLE 1. Quantitative information on specific root length, and rooth length density, l_{rv}, in literature. No = number in figure 1 L/Y_D = specific root length, [m/g]; $2R_o$ = average root diameter, [mm]; L_{ra} = total root length per unit soil surface area, [cm/cm^2] L_{rv} = root length density, [cm/cm^3]: I. average over rooted zone. II 0-30, III 30-60 and IV 60-90 cm depth.
(1) = as quoted in Brown and Scott (1985), (2) = as quoted in Nye and Tinker(1978), (3) = as quoted in Brown and Biscoe (1985), (4) = as quoted in Burch (1979).
VAR* column indicates the main source of variation in each publication: S = Soil type, D = date, F = fertilitry status, T = soil tillage, V = Cultivar, W = Watering regime.

REFERENCE	CROP/cv.	AGE	METHOD	DEPTH	VAR*	No	L/Y_D	$2R_o$	L_{ra}	L_{rv}I	L_{rv}II	L_{rv}III	L_{rv}IV
MONOCOTYLEDONAE													
WHEAT													
Barraclough, 1984	cv Hustler	June 80	core	100	SD	01	163	--	272	2.7	6.2	1.7	0.9
Barraclough, 1984	cv Hustler	June 80	core	100	SD	02	196	--	240	2.4	5.3	2.0	0.55
Barraclough, 1984	cv Hustler	June 81	core	100	SD	03	195	--	283	2.8	3.7	1.5	0.75
Barraclough, 1984	cv Hustler	June 81	core	100	SD	04	243	--	380	3.8	7.6	1.9	0.2
Cumbus, 1985	cv Gamenya	17 d	water cul.	--	F	05	162/159	--	--	--	•		
Gregory, 1979	--	May/Ju.	endoscope	100		--	--	--	60/90	1.0/2.0			
Gregory, 1978	•	17 June	core	150		--	--	--	223	1.5	4.6	1.7	0.8
Stankov, 1976	--	--	core	50		--	--	--	--	4.65	•		
Alston, 1980	Halberd	mature	core	34		--	--	--	--	3.6	3.3	--	--
Proffitt, 1985	cv SST 33	126 d	core	160		--	--	--	--	0.23	0.46	0.27	0.07
Chaudhary, 1983	-	70 d	--	90		--	--	--	--	1.6	8.6	3.7	1.95
Welbank, 1974 (2)	--	38/94 d	--	100		--	--	--	--	--	0.4/2.2	0/1.1	0/0.3
Andrews, 1969	--	--	soil	--		--	--	0.18	--	26			
De Willigen, 1987	cv Arminda	20/6/86	core	20		06	70/101	0.33	--	--			
De Willigen, 1987	cv Arminda	15/8/86	core	70		--	268	--	--	4.2			
BARLEY													
Drew, 1980	spring barley	30/65 Zadoks	core	20	TF	07	112	--	56	2.8			
Drew, 1980	spring barley	30/65 Zadoks	core	20	TF	08	162	--	104	5.2	•		
Aboulroos, 1979	--	35 d	pot	--		09	165	--	--	--	•		
Soileau, 1973	--	31 d	pot	--		10	202	--	--	12	12		
Stankov, 1976	--	--	core	50		--	--	--	--	4.7	•		
Kirby, 1971 (2)	--	ripe	--	140		--	--	--	--	--	1.6	0.7	0.3
OATS													
De Willigen, 1987	-	20/9/86	monolith	40		1	21	0.22		8.75			

REFERENCE	CROP/cv.	AGE	METHOD	DEPTH	VAR*	No	L/Y_D	$2R_o$	L_{ra}	$L_{rv}I$	$L_{rv}II$	$L_{rv}III$	$L_{rv}IV$
OATS (continued)													
Köpke, 1979	--	5 wk	monolith	50		12	97	0.22	1.7	0.34	1.08	0.55	0.03
Ehlers, 1980	--	18-5/22-6	profile	100		--	--	--	--	--	0.59	0.47	0.01
Ehlers, 1983	cv Leande	June	profile	75		--	--	--	14/64	0.16/0.71	1.0/1.8	0.2/?	0.1/?
Steinhardt, 1982	--	71 d	core	90		--	--	--	--	0.49	0.16	0.06	0.02
Stankov, 1976	--	--	core	50		--	--	--	--	0.08	.		
RICE													
Niranjan Rao , 1977	cv Earlirose	21 d	water cul.	--		13	12	--	--	--	.		
Hairiah, 1986	cv ITA 307	3,5,9,16 wk	pinb.	70		14	71	--	--	0.34	1.2/.7	0.2/sp	sp/.
MAIZE													
Follett, 1974	cv Pioneer 3935	2.5 mth	monolith	91	W	15	9.7	--	--	--	.		
Follett, 1974	cv Pioneer 3935	2.5 mth	monolith	91	W	16	8.2	--	--	--	.		
Follett, 1974	cv Pioneer 3935	2.5 mth	monolith	91	W	17	8.3	--	--	--	.		
Nielson, 1978	16 genotypes	21 d	water cul.	--		18	169	--	--	--	.		
Allmaras, 1975	cv DeKalb XL-4	5 August	monolith	145		19	30	--	--	--	.		
Mengel, 1974	--	90 d	core	75		20	101	--	112	1.5	26	3.0	1.6
MacKay, 1984	cv Pioneer3369A	28 d	water cul.	--		21	127	0.19	--	--	.		
Robertson, 1980	MC Nair 508	--	core	150		--	--	--	75	0.50	1.4/4.4	.1/.7	.1/.4
Shierlaw, 1984	Kretek	18 d	pot	--		--	--	--	--	5.7	.		
Reid, 1981	--	25 d	pot	--		--	--	--	--	9.5	.		
Schenk, 1979	5 cultivars	23 d	pot	--		22	81	--	--	2.8/8.7	.		
Jungk, 1974	--	12 d	water cul.	--		23	131	--	--	--	.		
Schenk, 1979	Pioneer 3369A	23 d	pot	--		24	108	0.21	--	5.0/12	.		
Warncke, 1974	--	18-81 d	water cul.	--		25	214	--	--	--			
De Willigen, 1987	cv Brutus	35 d	water cul.	--		26	280	--	--	--	.		
Carithers, 1981 (1)	--	60-100 d	--	--		--	--	--	--	1.4	1.4/.9	1.4/1 7	--
Grimes, 1975	pag sx-17	12 wk	core	183		--	--	--	--	2.0	4.2/8.2	3.0/. 8	2.1/.41
Schenk, 1980	3 cultivars	68 d	core	70		--	--	--	--	2.75	2.9	2.3	
Foth, 1962 (2)	--	37/100 d	--	45		--	--	--	--	--	0.0/5.2	0.1/0 6	0/0.1
Hairiah, 1986	--	2,48,14, wk	monolith	40		27	50	--	--	1.3	1.3	--	--
Taylor, 1973 (3)	--	--	--	180		--	--	--	--	3.9	7.4	4.1	3.5
SORGHUM													
Merrill, 1979	cv Pioneer 887	80 d	lysimeter	--		28	201	--	906	8.4	16	10	6.5
Hackett, 1973	cv TexasRS-61	17 d	pot	--		29	281	0.20	182	1.8	.		
Gardner, 1964	Milo	--	pot	120		--	--	--	59	0.49	0.83	0.46	0.31

REFERENCE	CROP/cv.	AGE	METHOD	DEPTH	VAR*	No	L/Y_D	$2R_o$	L_{ra}	$L_{rv}I$	$L_{rv}II$	$L_{rv}III$	$L_{rv}IV$
GRASS													
Clapp, 1984	Festuca arund.	5 yr	core	75		30	428	--	197	2.6	5.4	1.1	0.4
Garwood, 1979	Festuca arund.	1-2 yr	core	60		31	223	--	804	13.4	21.2	5.6	--
Burch, 1979	Festuca arund.		pot	--		--	--	0.19	--	0.7	.		
Clapp. 1984	Poa pratensis	5 yr	core	75		32	662	--	203	2.7	6.1	0.6	0.7
Reid, 1981	Lolium perenne	42 d	pot	--		--	--	--	--	25.6	.		
Hansen, 1974 (4)	Lolium multif.	--	soil	--		--	--	0.1	--	18.3	.		
De Willigen, 1987	Lolium perenn.	1-3 mth	pot	--		33	251	0.17	--	--	.		
Powell, 1977	Lolium perenn.	14-62 d	pot	--		34	465	--	--	--	.		
Garwood, 1979	Lolium perenn.	1-2 yr	core	60		35	356	--	1254	20.9	36.7	5.2	
Gilbert, 1984	L.rigidium cv	40 d	pot	--	F	36	723/383	0.23/0.29	--	--	.		
Robinson, 1985	Holcus lanatus	70 d	pot	--		37	198	0.13	--	0.84	.		
Robinson, 1985	Deschampsia f.	70 d	pot	--		38	161	0.10	--	0.84	.		
Garwood, 1979	Phleum praten.	1-2 yr	core	60		39	431	--	1272	21.2	39.8	2.6	--
Clapp, 1984	Phalaris arun.	5 yr	core	75		40	342	--	191	2.55	5.0	1.1	0.5
Clapp, 1984	Dactylis glom.	5 yr	core	75		41	408	--	117	1.56	3.4	0.4	0.2
Garwood, 1979	Dactylis glom.	1-2 yr	core	60		42	329	--	978	16.3	29.2	3.2	--
CAREX CORIACEA													
Powell, 1974	--	95 d	pot	--		43	308	0.11					
DICOTYLEDONAE													
SUGAR BEET													
Brown, 1985	--	sept.	core	40		44	122	--	--	0.13	1.6/1.4	--	--
De Willigen, 1987	--	16/7/86	water cul.	--		45	741/486	0.17/0.24	--	--	--	--	--
De Willigen, 1987	--	4/8/82	core	90		--	316	0.17/0.24	--	--	.		
De Willigen, 1987	--	4/8/82	core	90		--	316	0.17	--	1.03	1.8	0.82	0.47
De Willigen, 1987	--	1/8/85	core	70		--	--	--	--	.	2.09	0.37	--
De Willigen, 1987	--	10/9/85	monolith	70		--	235	0.29	--	1.32	1.54	0.29	--
CARNATION													
De Willigen, 1987	cv castellaro	may '86	rockwool	--		46	76	0.36	--	--			
De Willigen, 1987	cv westpink	may '86	pot	--		47	12	0.54	--	--			
CASSAVA													
Hairiah, 1986	--	2,5,8,14 wk	pinboard	40		48	23	--	--	0.5	0.7	--	--
Connor, 1981 (3)	--	--	-	--		--	--	--	--	0.7	0.2	0.04	0.02
ANEMONE													
De Willigen, 1987	anemone vijve.	may '86	pot	--		49	117	0.38	--	--			
De Willigen, 1987	anomene duind.	may '86	pot	--		50	114	0.42	--	--			

REFERENCE	CROP/cv.	AGE	METHOD	DEPTH	VAR*	No	L/Y_D	$2R_o$	L_{ra}	$L_{rv}I$	$L_{rv}II$	$L_{rv}III$	$L_{rv}IV$
COLZA													
Köpke, 1979		35 d	monolith	50		51	97						
SWEDE (TURNIP)													
Köpke, 1979	--	35 d	monolith	50		52	104		--				
ALFALFA (LUCERNE)													
Reid, 1981	--	42 d	pot	--		--	--	--	--	5.4	.		
De Willigen, 1987	--	8/11/84	core	80		--	--	--	--	1.9	4.4	0.44	0.18
Grimes, 1975	3 cultivars	16 wk	core	91		--	--	--	--	2.10	3.85	1.67	0.78
Abdul-Jabbar, 1984	--	bud stage	core	165		--	--	--	--	0.6			
CLOVER													
Pearson, 1985	Trif. subter.	119 d	core	50		53	75/206	--	0.77/1.8	0.34	.		
Gilbert, 1984	Trikkala	40 d	pot	--	F	54	289/212	0.32/0.36	--	--	.		
Caradus, 1986	white clover	23/17 d	water cul.	--	WV	55	70/101	--	--	--	.		
De Willigen, 1987	--	8/11/84	core	80		--	--	--	--	0.77	1.28	0.65	0.22
VETCH													
Kopke, 1979	--	35 d	monolith	50		56	90	--	--				
GROUND-NUTS													
Robertson, 1980	Florunner	95 d	core	150		--	--	--	--	0.5	1.6	0.6	0.6
Pandey, 1984	Kidnang	55 d	core	80		--	--	--	--	0.5	0.8	0.2	0.2
PEAS													
Stankov, 1976	--		core	50		--	--	--	--	2.14	3.57		
SOY-BEAN													
Garay, 1983	Harosoy	47-78 d	core	90/150		57	68	--	65.5	0.73	0.36	0.39	0.51
Riley, 1971	--	21 d	pot	--		58	152	--	--	--	.		
Borkert, 1985	--	20-24 d	pot	--		59	318	0.15	--	--	.		
Allmaras, 1975	Harosoy	august	monolith	80		60	29	--	9.5	.078	0.17	0.075	0.048
Borkert, 1983	--	25 d	water cul.	--		61	260	0.16	--	--	.		
Raper, 1970	Aoda/Harosoy63	--	core	80		--	--	--	--	.02/.03	.03/.05	.02	.02
Sivakumar, 1977	--	V15R2	monolith	180		--	--	--	25	.14	.17	.003	.049
Robertson, 1980	Cobb	--	core	150		--	--	--	--	0.5	1.2	0.4	0.5
Pandey, 1984	u plsy-2	55 d	core	80		--	--	--	--	0.4	0.9	0.2	0.1
Sanders, 1978	Lee-68	R7 stage	core/scope	72		--	--	--	--	.85/.81	7.4	0.99	1.52
Brown, 1985	Lee-74/Sohoma	R4 stage	--	60		--	--	--	--	2.3/2.1	3.1/2.7	1.0/1.2	--
Böhm, 1977	Wayne	47 d	monolith	90		--	--	--	9	0.10	--	--	--
Arya, 1975	P179.648	91 d	core	80		--	--	--	129	1.61	1.82	1.73	1.12
Taylor, 1976	Corosoy	84 d	core	188		--	--	--	126	0.67	--	0.80	0.76

REFERENCE	CROP/cv.	AGE	METHOD	DEPTH	VAR*	No	L/Y_D	$2R_o$	L_{ra}	$L_{rv}I$	$L_{rv}II$	$L_{rv}III$	$L_{rv}IV$
SOY-BEAN (continued)													
Cappy, 1979 (1)	Forrest	R4 stage	??	70	--	--		--	32	0.45	0.4	0.4	0.6
Geddes, 1979	Lee 74	12 wk	core	90	--	--		--	--	0.88	1.8	0.6	0.4
Brown, 1985	4 cultivars	R2/R4	scope	64	--	--		--	243	3.8	5.8	1.7	--
Scott, 1976	Lee 68	12 wk	core	100	--	--		--	--	0.02	2.9	sp	0.1
BEANS													
Stankov, 1976	--	--	core	50	--	--		--	--	2.20	3.66		
Reid, 1984	--	--	--		--	--		--	--	10.1	17.1	6.0	1.67
Pandey, 1984	mungbeanCes-ID	55 d	core	80	--	--		--	--	0.5	1.3	0.3	0.1
Pandey, 1984	cowpea EG no.2	55 d	core	80	--	--		--	--	0.5	0.2	0.2	0.2
COTTON													
Taylor, 1974	Auburn 623b	10-14 wk	rhizotron	180	62	96		--	--	0.9	2.9/.3/.6	1.8/.9/.6	.6/1.6/-
Grimes, 1975	Acala SJ-1	19 wk	core	183	--	--		--	185	1.01	2.33	1.99	1.50
Cappy, 1979 (1)	Rex 713	4 stages	scope	126	--	--		--	--	.42	0.42		
Klepper, 1973	Cotton	29 July	--	180	--	--		--	--	1.3/1.8	2.3/1.1	1.6	1.3/1.6
Taylor, 1975 (4)	--	--	soil	--	--	--		0.25	--	2.7	.		
POTATO													
De Willigen, 1987	--	--	monolith	20	63	234		0.28	--	--	.		
De Willigen, 1987	--	12/7/82	core	60	--	--		--	--	.	1.61	0.71	--
Vos, 1986	cv Bintje	--	core	100	--	--		--	40	0.8	1.5	0.7	0.2
TOMATO													
De Willigen, 19874	cv Moneymaker	9-19	water cul.	--	64	312		--		--			
De Willigen, 1987	cv Moneymaker	7-16	water cul.	--	65	372		0.22		--			
De Willigen, 1987	cv Moneymaker	115	water cul.	--	66	378		--		--			
CUCUMBER													
De Willigen, 1987	cv Corona	6-12 wk	water cul.	--	67	437		--	--	--			
De Willigen, 1987	cv Corona	5-14 wk	water cul.	--	68	494		0.24	--	--			
De Willigen, 1987	--	adult	rockwool	--	69	382		--	--	--			
De Willigen, 1987	cv Corona	5-14 wk	water cul.	--	70	444		0.12/0.23	--	--			
FLAX													
Stankov, 1976	--		core	50						5.5	9.2		
IPOMOEA													
Scott, 1976	--	12 wk	core	100						2.13	4.74	0.73	1.14
LETTUCE													
De Willigen, 1987	cv Plevanos	5 wk	water cul.	--	71	284		0.37	--	--			
Rowse, 1974	cv Borough Won.	68 d	core	55	--	--		--	--	0.62	0.77		

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