THE DEPENDENCE OF YIELD ON ASYMMETRY IN COCONUT PALMS

By T. A. DAVIS
Indian Statistical Institute, Calcutta-35

Introduction

The main result here recorded is that coconut (*Cocos nucifera* L.) trees with a left-handed foliar spiral yield, on an average, more nuts per year than those with a right-handed spiral. It is of course, likely that similar results will be obtained in other organisms. However, as the result appears to be unprecedented, I have published the data rather more fully than would be justifiable were I dealing with the effects of a manurial treatment or a gene substitution.

I previously (Davis, 1962a and 1962b) mentioned that the leaves of coconut palms are arranged in five right-handed or left-handed spirals, that the two types of trees are almost equally common, and that the difference is certainly not inherited, and probably not determined genetically. In view of the finding that asymmetry has an important effect on yield, I add some further data on the genetics and frequency of the two types, which confirm my former results.

History of the Experiment

In India about 7,200 square kilometres (1·77 million acres) are under coconuts, this being 20 per cent of the world area. Two-thirds of the Indian area is in the state of Kerala, and over 10 percent of the Kerala area is affected by a major disease, the root (wilt), responsible for an annual loss of some ten million rupees. It was desired to find out how far certain 'micronutrients' could prevent or control this disease. For this purpose an experiment was set up at the Central Coconut Research Station, Kayangulam. Half the trees were treated with Mg (A), half with B (B), half with Cu (C), half with Mn (D), half with Fe (E), half with Mo (F) and half with Zn (G). The design is a "2^7 confounded design" comprising 128 treatments, for example treatment A D E G means treatment with Mg, Mn, Fe and Zn only. Each such treatment was applied to three trees, one healthy, one in the early stage, and one in the late stage of the disease. Thus the experiment involved 384 trees. Each of these trees, and many other trees standing in a 8 hectare (20 acres) field, received a basal manurial dose of 0·75 lb nitrogen as groundnut cake, 0·75 lb phosphoric acid as bone meal, and 1·5 lb of potash as "muriate of potash" (KCl) per year. The whole area received an annual dressing of 2 cwts slaked lime per acre, and each year a green manure crop was raised and incorporated uniformly into the soil.

The treatments were applied annually in shallow trenches round the bases of the stems. The experimental trees were so selected that none stood close to another. There are 16 main plots each containing 8 healthy trees, 8 with the early symptoms of disease, and 8 in the late stage. It was not possible to find, in each plot, isolated trees of the desired health category and the same age. More importance was attached to the category of the trees, and the age varied from 15 to 65 years.

From 1953 to 1960 I was in charge of this experiment, and can vouch for the accuracy of the data. There are records of the spreading and shedding of every leaf, measurements of leaves and counts of leaflets, opening of spadices, numbers of female flowers, numbers of nuts matured, etc. However the weight of nuts from individual trees was not recorded. Besides this, data on the yield of nuts from each tree from 1949 to 1952 inclusive are available. I do not doubt that they are substantially correct, but have reason to think that some nuts were stolen. The micronutrients were first applied in September 1953, and it was first intended to continue it for 5 years only. However, since no significant effect of any treatment was found, it was decided to continue it for another five years.

As the data on nut yields were available, I decided to see whether the non-inherited asymmetry had anything to do with the yield. Each palm was classified for its leaf spiral and I found, to my very great surprise, the large effects shown in Figs. 1 to 3. Before discussing these it will be desirable to describe some tests made for possible bias.

TESTS FOR BIAS

The trees were chosen without regard to their spirality. 177 of the 384 were Lefts. In future I shall use the words Lefts and Rights to mean trees with left-handed or right-handed foliar spirals. The expectation on a basis of equality is $192 \pm 9{\cdot}8$. The excess of Rights is not significant at the 5 percent level. Each of the 48 sub-plots contained 8 trees, all healthy or all in the early or late stages of the disease. The numbers of sub-plots containing a given number of Lefts are given in Table 1.

Table 1

Lefts ..	0	1	2	3	4	5	6	7	8
Plots found ..	1	1	6	14	14	8	3	0	1
Plots expected ..	0·34	2·34	7·01	11·98	12·80	8·76	3·75	0·92	0·10

The number of plots expected with n lefts is $\binom{8}{n} \dfrac{48.59^n.69^{8-n}}{128^8}$

It is a little unexpected that even one plot was found with 8 Lefts, however the variance of the number of Lefts is 1·969, the expected value being $\dfrac{8 \times 177 \times 207}{384^2} = 1{\cdot}988$. Thus the Lefts and Rights were adequately randomized as between blocks. With regard to treatments I have only tested randomness for the healthy palms, as these alone showed a significant excess of nuts on Lefts. Among the 128 healthy trees 29 Lefts and 35 Rights received treatments A, 29 Lefts and 35 Rights did not. This we get in Table 2(a), where a means treatment A not received.

Table 2

(a)

	L	R
A	29	35
a	29	35

$\chi^2_1=0$

(b)

	L	R
B	32	32
b	26	38

$\chi^2_1=1{\cdot}1350$

(c)

	L	R
C	28	36
c	30	34

$\chi^2_1=0{\cdot}1261$

(d)

	L	R
D	27	37
d	31	33

$\chi^2_1=0{\cdot}5044$

(e)

	L	R
E	37	27
e	21	43

$\chi^2_1=8{\cdot}0709$

(f)

	L	R
F	33	31
f	25	39

$\chi^2_1=2{\cdot}0177$

(g)

	L	R
G	31	33
g	27	37

$\chi^2_1=0{\cdot}5044$

Only one of these values, taken by itself, is significant of bias. The total $\chi^2_7=12{\cdot}3585$, giving P=·10, which is not significant. In spite of the curious association of Lefts with an iron supplement, I think the randomization was adequate.

Treatment of Exceptions

The yields of all 384 trees from 1949 to 1960 were tabulated. The tables contain 6144 entries, and I hope to publish them when the analysis of various interactions is completed. The data have been condensed in Tables 3, 4 and 5, and the graphs show further features.

Three of the 384 trees, one Left and two Rights, gave no nuts at all during the 12 years. They were all diseased. Had they been included they would have slightly increased the excess yield of Lefts over the Rights. Thus, had they been included the evidence for the superiority of Lefts would be slightly stronger. Of the remaining 381, 3 healthy and 3 diseased trees died through lightning and disease between 1956 and 1959. For these 6 trees the average given in Tables 3 to 5 were based on the years before their deaths. The nuts are harvested 8 times per year, and partial yields in the year when a tree died are omitted. A few other trees only started producing after 1949. These trees were treated like those which died. But in the case of the 128 healthy trees this adjustment only affects the pre-treatment yield, while it is the post-treatment yields which are more accurate and differ more significantly between Lefts and Rights. As it happens two of the healthy palms which died were Rights and one a Left. If the data had not been adjusted, the yield of the Lefts would therefore have been relatively higher.

Table 3a. *Nut yield of Coconut palms. I. Healthy (Left-handers)*

	Tree No.	Age in 1953	Yield for 1949-1960 (12 years)		Pre-treatment yield (1949-1954)		Post-treatment yield (1955-1960)	
			Total	Average	Total	Average	Total	Average
1	58	40	581	48·42	243	40·50	338	56·33
2	104	55	980	81·67	538	89·67	442	73·67
3	75	55	912	76·00	470	78·33	442	73·67
4	154	45	1283	106·92	600	100·00	683	113·83
5	52	40	470	39·17	231	38·50	239	39·83
6	63	40	761	63·42	315	52·50	446	74·33
7	78	50	799	66·58	410	68·33	389	64·83
8	87	50	873	72·75	440	73·33	433	72·17
9	42	50	735	61·25	332	55·33	403	67·17
10	3	30	464	38·67	167	27·83	297	49·50
11	150	50	536	44·67	329	54·83	207	34·50
12	133	60	728	60·67	339	56·50	389	64·83
13	251	50	471	39·25	196	32·67	275	45·83
14	232	50	781	65·08	349	58·17	432	72·00
15	322	55	1266	105·50	574	95·67	692	115·33
16	279	45	715	59·58	324	54·00	391	65·17
17	254	50	1026	85·50	463	77·17	563	93·83
18	265	50	402	33·50	183	30·50	219	36·50
19	189	55	874	72·83	416	69·33	458	76·33
20	210	50	770	64·17	315	52·50	455	75·83
21	303	60	784	65·33	424	70·67	360	60·00
22	215	40	360	30·00	97	16·17	263	43·83
23	208	55	473	39·42	187	31·17	286	47·67
24	206	30	373	31·08	128	21·33	245	40·83
25	380	25	1147	95·58	430	71·67	717	119·50
26	391	25	1356	113·00	522	87·00	834	139·00
27	310	60	774	64·50	344	57·33	430	71·67
28	416	50	256	21·33	112	18·67	144	24·00
29	354	35	496	41·33	138	23·00	358	59·67
30	408	40	584	48·67	298	49·67	286	47·67
31	358	60	669	55·75	285	47·50	384	64·00
32	288	65	445	37·08	227	37·83	218	36·33
33	421	45	628	52·33	308	51·33	320	53·33
34	276	40	710	59·17	275	45·83	435	72·50
35	345	45	540	45·00	225	37·50	315	52·50
36	463	35	740	61·67	83	13·83	657	109·50
37	191	60	737	61·42	367	61·17	370	61·67
38	438	50	703	58·58	342	57·00	361	60·17
39	388	50	348	29·00	168	28·00	180	30·00
40	232	60	377	31·42	133	22·17	244	40·67
41	254	20	699	58·25	216	36·00	483	80·50
42	289	35	667	55·58	314	52·33	353	58·83
43	282	35	645	53·75	253	42·17	392	65·33
44	292	60	488	40·67	232	38·67	256	42·67
45	15	50	898	74·83	416	69·33	482	80·33
46	298	45	213	17·75	81	13·50	132	22·00
47	362	60	703	58·58	325	54·17	378	63·00
48	110	30	651	54·25	250	41·67	401	66·83
49	241	35	347	28·92	72	12·00	275	45·83
50	4	55	462	38·50	223	37·17	239	39·83

Table 3a. *Nut yield of Coconut palms. I. Healthy (Left-handers)*—Contd.

	Tree no.	Age in 1953	Yield for 1949-60 (12 years)		Pre-treatment yield (1949-1954)		Post-treatment yield (1955-1960)	
			Total	Average	Total	Average	Total	Average
51	192	25	957	79·75	368	61·33	589	98·17
52	113	45	1117	93·08	479	79·83	638	106·33
53	70	30	786	65·50	269	44·83	517	86·17
54	105	25	812	67·67	271	45·17	541	90·17
55	44	45	711	59·25	360	60·00	351	58·50
56	28	35	730	60·83	284	47·33	446	74·33
57	148	50	839	69·92	326	54·33	513	85·50
58	136	50	502	41·83	258	43·00	244	40·67

Table 3b. *Nut yield of Coconut palms. I. Healthy (Right-handers)*

	Tree No.	Age in 1953	Yield for 1949-1960 (12 years)		Pre-treatment yield (1949-1954)		Post-treatment yield (1955-1960)	
			Total	Average	Total	Average	Total	Average
1	55	40	217	18·08	94	15·67	123	20·50
2	120	55	663	55·25	371	61·83	292	48·67
3	79	55	260	21·67	168	28·00	92	15·33
4	54	45	762	63·50	365	60·83	397	66·17
5	36	45	842	70·17	449	74·83	393	65·50
6	19	40	655	54·58	322	53·67	333	55·50
7	115	55	576	48·00	316	52·67	260	43·33
8	33	45	879	73·25	419	69·83	460	76·67
9	53	45	612	51·00	347	57·83	265	44·17
10	66	45	722	60·17	380	63·33	342	57·00
11	46	45	873	72·75	357	59·50	516	86·00
12	81	55	713	59·42	341	56·83	372	62·00
13	48	45	930	77·50	474	79·00	456	76·00
14	31	40	864	72·00	395	65·83	469	78·17
15	116	40	557	46·42	193	32·17	364	60·67
16	48A	25	571	47·58	181	30·17	390	65·00
17	95	55	885	73·75	457	76·17	428	71·33
18	138	20	542	45·17	216	36·00	326	54·33
19	89	50	1110	92·50	518	86·33	592	98·67
20	83	25	240	20·00	39	6·50	201	33·50
21	114	25	210	17·50	78	13·00	132	22·00
22	129	50	627	52·25	278	46·33	349	58·17
23	45	40	563	46·92	172	28·67	391	65·17
24	149	45	740	61·67	332	55·33	408	68·00
25	99	65	628	52·33	343	57·17	285	47·50
26	118	45	626	52·17	272	45·33	354	59·00
27	91	65	731	60·92	321	53·50	410	68·33
28	90	65	648	54·00	268	44·67	380	63·33
29	270	50	813	67·75	400	66·67	413	68·83
30	274	50	829	69·08	381	63·50	448	74·67
31	302	60	499	41·58	224	37·33	275	45·83
32	295	35	318	26·50	106	17·67	212	35·33
33	405	50	479	39·92	199	33·17	280	46·67
34	330	45	428	35·67	197	32·83	231	38·50
35	327	40	622	51·83	306	51·00	316	52·67

Table 3b. *Nut yield of Coconut palms. I. Healthy (Right-handers)*—Contd.

	Tree no.	Age in 1953	Yield for 1949-60 (12 years)		Pre-treatment yield (1949-1954)		Post-treatment yield (1955-1960)	
			Total	Average	Total	Average	Total	Average
36	178	55	311	25·92	119	19·83	192	32·00
37	260	45	339	28·25	144	24·00	195	32·50
38	404	50	379	31·58	220	36·67	159	26·50
39	323	55	650	54·17	271	45·17	379	63·17
40	190	50	602	50·17	314	52·33	288	48·00
41	307	25	342	28·50	202	33·67	140	23·33
42	344	40	612	51·00	320	53·33	292	48·67
43	398	30	429	35·75	150	25·00	279	46·50
44	273	20	566	47·17	186	31·00	380	63·33
45	249	25	264	22·00	42	7·00	222	37·00
46	392	40	487	40·58	153	25·50	334	55·67
47	240	50	381	31·75	237	39·50	144	24·00
48	299	35	758	63·17	254	42·33	504	84·00
49	291	45	772	64·33	352	58·67	420	70·00
50	169	55	482	40·17	227	37·83	255	42·50
51	367	50	432	36·00	181	30·17	251	41·83
52	359	65	501	41·75	260	43·33	241	40·17
53	361	60	707	58·92	359	59·83	348	58·00
54	354	55	732	61·00	303	50·50	429	71·50
55	96	55	613	51·08	236	39·33	377	62·83
56	365	55	483	40·25	99	16·50	384	64·00
57	211	45	1108	92·33	568	94·67	540	90·00
58	218	45	551	45·92	276	46·00	275	45·83
59	188	25	213	17·75	143	23·83	70	11·67
60	186	25	276	23·00	123	20·50	153	25·50
61	199	50	454	37·83	201	33·50	253	42·17
62	94	55	544	45·33	272	45·33	272	45·33
63	125	30	654	54·50	318	53·00	336	56·00
64	102	35	987	82·25	423	70·50	564	94·00
65	79A	30	1195	99·58	471	78·50	724	120·67
66	126	40	821	68·42	375	62·50	446	74·33
67	133	50	757	63·08	366	61·00	391	65·17
68	48B	30	69	5·75	30	5·00	39	6·50
69	3	25	555	46·25	341	56·83	214	35·67
70	141	45	593	49·42	240	40·00	353	58·83

Table 4a. *Nut yield of Coconut palms. II. Early disease (Left-handers)*

	Tree no.	Age in 1953	Yield for 1949-1960 (12 years)		Pre-treatment yield (1949-1954)		Post-treatment yield (1955-1960)	
			Total	Average	Total	Average	Total	Average
1	153	45	393	32·75	117	19·50	276	46·00
2	59	45	10	0·83	8	1·33	2	0·33
3	144	55	451	37·58	260	43·33	191	31·83
4	122	55	473	39·42	222	37·00	251	41·83
5	39	45	603	50·25	235	39·17	368	61·33
6	91	40	216	18·00	78	13·00	138	23·00
7	34	45	338	28·17	145	24·17	193	32·17
8	83	50	689	57·42	341	56·83	348	58·00
9	93	40	666	55·50	353	58·83	313	52·17
10	80	20	26	2·17	20	3·33	6	1·00

Table 4a. *Nut yield of Coconut palms. II. Early disease (Left-handers)*—Contd.

	Tree no.	Age in 1953	Yield for 1949-60 (12 years)		Pre-treatment yield (1949-1954)		Post-treatment yield (1955-1960)	
			Total	Average	Total	Average	Total	Average
11	29	35	452	37·67	174	29·00	278	46·33
12	13	40	502	41·83	190	31·67	312	52·00
13	166	45	373	31·08	160	26·67	213	35·50
14	165	60	351	29·25	136	22·67	215	35·83
15	58	40	510	42·50	196	32·67	314	52·33
16	42	45	696	58·00	486	81·00	210	35·00
17	103	65	407	33·92	236	39·33	171	28·50
18	285	55	345	28·75	149	24·83	196	32·67
19	224	35	379	31·58	180	30·00	199	33·17
20	227	50	226	18·83	138	23·00	88	14·67
21	216	45	140	11·67	47	7·83	93	15·50
22	223	50	448	37·33	180	30·00	268	44·67
23	217	50	361	30·08	124	20·67	237	39·50
24	293	35	271	22·58	23	3·83	248	41·33
25	219	50	463	38·58	206	34·33	257	42·83
26	299	60	434	36·17	203	33·83	231	38·50
27	32	35	304	25·33	99	16·50	205	34·17
28	218	50	396	33·00	168	28·00	228	38·00
29	346	65	372	31·00	224	37·33	148	24·67
30	328	45	606	50·50	294	49·00	312	52·00
31	320	55	315	26·25	114	19·00	201	33·50
32	412	35	89	7·42	47	7·83	42	7·00
33	424	25	320	26·67	90	15·00	230	38·33
34	429	50	849	70·75	379	63·17	470	78·33
35	458	35	337	28·08	94	15·67	243	40·50
36	322	65	278	23·17	128	21·33	150	25·00
37	446	40	416	34·67	172	28·67	244	40·67
38	450	30	110	9·17	68	11·33	42	7·00
39	391	30	260	21·67	100	16·67	160	26·67
40	397	50	588	49·00	293	48·83	295	49·17
41	394	30	241	20·08	149	24·83	92	15·33
42	387	35	37	3·08	9	1·50	28	4·67
43	209	20	156	13·00	46	7·67	110	18·33
44	285	25	21	1·75	..	..	21	3·50
45	360	55	398	33·17	233	38·83	165	27·50
46	348	35	482	40·17	193	32·17	289	48·17
47	368	45	311	25·92	195	32·50	116	19·33
48	370	30	292	24·33	95	15·83	197	32·83
49	376	45	381	31·75	143	23·83	238	39·67
50	206	40	374	31·17	143	23·83	231	38·50
51	229	45	571	47·58	286	47·67	285	47·50
52	128	55	1156	96·33	589	98·17	567	94·50
53	230	60	271	22·58	106	17·67	165	27·50
54	121	50	353	29·42	174	29·00	179	29·83
55	123	40	400	33·33	111	18·50	289	48·17
56	100	55	483	40·25	229	38·17	254	42·33
57	90	50	331	27·58	156	26·00	175	29·17
58	159	50	641	53·42	291	48·50	350	58·33
59	54	25	172	14·33	36	6·00	136	22·67
60	146	35	845	70·42	361	60·17	484	80·67
61	35	30	366	30·50	146	24·33	220	36·67

Table 4b. *Nut yield of Coconut palms. II. Early disease (Right-handers)*

	Tree no.	Age in 1955	Yield for 1949-1960 (12 years)		Pre-treatment yield (1949-1954)		Post-treatment yield (1955-1960)	
			Total	Average	Total	Average	Total	Average
1	61	40	429	35·75	212	35·33	217	36·17
2	145	45	269	22·42	222	37·00	47	7·83
3	38	50	866	72·17	378	63·00	488	81·33
4	76	50	124	10·33	55	9·17	69	11·50
5	117	40	370	30·83	185	30·83	185	30·83
6	77	55	156	13·00	103	17·17	53	8·83
7	106	50	193	16·08	100	16·67	93	15·50
8	41	45	228	19·00	218	36·33	10	1·67
9	113	55	308	25·67	168	28·00	140	23·33
10	16	45	262	21·83	141	23·50	121	20·17
11	32	45	560	46·67	267	44·50	293	48·83
12	47	35	355	29·58	164	27·33	191	31·83
13	17	45	222	18·50	110	18·33	112	18·67
14	99	45	979	81·58	445	74·17	534	89·00
15	98	45	199	16·58	92	15·33	107	17·83
16	14	45	226	18·83	160	26·67	66	11·00
17	15	30	639	53·25	311	51·83	328	54·67
18	123	45	133	11·08	40	6·67	93	15·50
19	125	50	342	28·50	161	26·83	181	30·17
20	72	45	524	43·67	178	29·67	346	57·67
21	44	40	549	45·75	227	37·83	322	53·67
22	57	50	330	27·50	162	27·00	168	28·00
23	31	40	329	27·42	118	19·67	211	35·17
24	255	50	406	33·83	206	34·33	200	33·33
25	286	55	581	48·42	269	44·83	312	52·00
26	281	65	442	36·83	197	32·83	245	40·83
27	262	35	779	64·92	316	52·67	463	77·17
28	269	50	274	22·83	193	32·17	81	13·50
29	382	30	283	23·58	113	18·83	170	28·33
30	319	60	367	30·58	218	36·33	149	24·83
31	383	55	196	16·33	108	18·00	88	14·67
32	402	65	667	55·58	315	52·50	352	58·67
33	321	55	174	14·50	69	11·50	105	17·50
34	409	35	456	38·00	138	23·00	318	53·00
35	423	30	343	28·58	26	4·33	317	52·83
36	433	45	750	62·50	301	50·17	449	74·83
37	427	50	121	10·08	34	5·67	87	14·50
38	407	35	269	22·42	153	25·50	116	19·33
39	321	60	472	39·33	203	33·83	269	44·83
40	335	40	202	16·83	99	16·50	103	17·17
41	449	50	148	12·33	43	7·17	105	17·50
42	456	55	581	48·42	246	41·00	335	55·83
43	396	25	40	3·33	..	..	40	6·67
44	231	25	118	9·83	42	7·00	76	12·67
45	256	40	847	70·58	426	71·00	421	70·17
46	395	45	525	43·75	224	37·33	301	50·17
47	293	50	208	17·33	116	19·33	92	15·33
48	301	35	401	33·42	156	26·00	245	40·83
49	294	50	407	33·92	184	30·67	223	37·17
50	268	60	522	43·50	260	43·33	262	43·67

Table 4b. *Nut yield of Coconut palms. II. Early disease (Right-handers)*—Contd.

	Tree no.	Age in 1953	Yield for 1949-1960 (12 years)		Pre-treatment yield (1949-1954)		Post-treatment yield (1955-1960)	
			Total	Average	Total	Average	Total	Average
51	281	65	230	19·17	110	18·33	120	20·00
52	279	60	302	25·17	179	29·83	123	20·50
53	380	55	117	9·75	63	10·50	54	9·00
54	371	55	116	9·67	68	11·33	48	8·00
55	351	35	403	33·58	176	29·33	227	37·83
56	197	15	169	14·08	36	6·00	133	22·17
57	187	25	151	12·58	53	8·83	98	16·33
58	208	20	14	1·17	9	1·50	5	0·83
59	304	35	104	8·67	28	4·67	76	12·67
60	93	55	591	49·25	262	43·67	329	54·83
61	98	55	328	27·33	160	26·67	168	28·00
62	86	35	225	18·75	100	16·67	125	20·83
63	124	25	579	48·25	224	37·33	355	59·17
64	27	30	252	21·00	60	10·00	192	32·00
65	32	35	120	10·00	60	10·00	60	10·00
66	39	30	1168	97·33	512	85·33	656	109·33
67	134	50	198	16·50	119	19·83	79	13·17

Table 5a. *Nut yield of Coconut palms. III. Late disease (Left-handers)*

	Tree No.	Age in 1953	Yield for 1949-1960 (12 years)		Pre-treatment yield (1949-1954)		Post-treatment yield (1955-1960)	
			Total	Average	Total	Average	Total	Average
1	146	50	97	8·08	21	3·50	76	12·67
2	116	45	104	8·67	81	13·50	23	3·83
3	114	60	364	30·33	212	35·33	152	25·33
4	40	45	338	28·17	155	25·83	183	30·50
5	21	40	36	3·00	6	1·00	30	5·00
6	35	45	..	..	..	..	..	..
7	82	50	404	33·67	219	36·50	185	30·83
8	109	50	116	9·67	86	14·33	30	5·00
9	111	65	616	51·33	359	59·83	257	42·83
10	195	60	420	35·00	209	34·83	211	35·17
11	140	45	574	47·83	269	44·83	305	50·83
12	147	35	237	19·75	97	16·17	140	23·33
13	122	55	280	23·33	103	17·17	177	29·50
14	25	45	193	16·08	67	11·17	126	21·00
15	126	50	75	6·25	39	6·50	36	6·00
16	158	60	364	30·33	185	30·83	179	29·83
17	9	40	553	46·08	242	40·33	311	51·83
18	77	50	276	23·00	96	16·00	180	30·00
19	231	50	248	20·67	131	21·83	117	19·50
20	244	50	187	15·58	45	7·50	142	23·67
21	246	60	118	9·83	51	8·50	67	11·17
22	253	35	92	7·67	46	7·67	46	7·67
23	187	55	323	26·92	171	28·50	152	25·33
24	190	65	362	30·17	153	25·50	209	34·83
25	236	65	221	18·42	101	16·83	120	20·00

Table 5a. *Nut yield of Coconut palms. III. Late disease (Left-handers)*—Contd.

	Tree No.	Age in 1953	Yield for 1949-60 (12 years)		Pre-treatment yield (1949-1954)		Pre-treatment yield (1955-1960)	
			Total	Average	Total	Average	Total	Average
26	358	35	822	68·50	396	66·00	426	71·00
27	375	25	76	6·33	36	6·00	40	6·67
28	415	65	..	..	21	3·50	..	..
29	428	65	139	11·58	74	12·33	65	10·83
30	448	55	191	15·92	64	10·67	127	21·17
31	430	50	162	13·50	56	9·33	106	17·67
32	437	65	768	64·00	295	49·17	473	78·83
33	462	65	93	7·75	52	8·67	41	6·83
34	444	40	356	29·67	161	26·83	195	32·50
35	457	45	273	22·75	130	21·67	143	23·83
36	340	50	295	24·58	141	23·50	154	25·67
37	389	55	432	36·00	213	35·50	219	36·50
38	384	50	190	15·83	70	11·67	120	20·00
39	258	55	11	0·92	2	0·33	9	1·50
40	252	50	110	9·17	54	9·00	56	9·33
41	261	60	327	27·25	138	23·00	189	31·50
42	385	55	138	11·50	81	13·50	57	9·50
43	259	45	69	5·75	54	9·00	15	2·50
44	263	50	405	33·75	190	31·67	215	35·83
45	267	55	140	11·67	61	10·17	79	13·17
46	296	65	361	30·08	175	29·17	186	31·00
47	290	45	611	50·92	280	46·67	331	55·17
48	355	60	51	4·25	33	5·50	18	3·00
49	372	50	193	16·08	120	20·00	73	12·17
50	419	40	81	6·75	43	7·17	38	6·33
51	221	45	67	5·58	37	6·17	30	5·00
52	185	45	291	24·25	112	18·67	179	29·83
53	217	45	104	8·67	26	4·33	78	13·00
54	111	35	177	14·75	84	14·00	93	15·50
55	85	55	32	2·67	14	2·33	18	3·00
56	62	65	164	13·67	74	12·33	90	15·00
57	38	25	320	26·67	92	15·33	228	38·00
58	147	45	772	64·33	376	62·67	396	66·00

Table 5b. *Nut yield of Coconut palms. III. Late disease (Right-handers)*

	Tree no.	Age in 1953	Yield for 1949-1960 (12 years)		Pre-treatment yield (1949-1954)		Post-treatment yield (1955-1960)	
			Total	Average	Total	Average	Total	Average
1	23	45	601	50·08	320	53·33	281	46·83
2	103	50	299	24·92	129	21·50	170	28·33
3	152	45	390	32·50	188	31·33	202	33·67
4	123	55	226	18·83	171	28·50	55	9·17
5	140	55	241	20·08	159	26·50	82	13·67
6	124	40	42	3·50	17	2·83	25	4·17
7	138	65	334	27·83	135	22·50	199	33·17
8	51	60	135	11·25	74	12·33	61	10·17
9	93	50	199	16·58	132	22·00	67	11·17
10	139	40	471	39·25	207	34·50	264	44·00
11	129	40	639	53·25	290	48·33	349	58·17
12	29	45	25	2·08	9	1·50	16	2·67
13	18	55	4	0·33	2	0·33	2	0·33
14	28	55	33	2·75	26	4·33	7	1·17
15	12	40	609	50·75	314	52·33	295	49·17

Table 5b. *Nut yield of Coconut palms. III. Late disease (Right-handers)*—Contd.

	Tree no.	Age in 1953	Yield for 1949-1960 (12 years)		Pre-treatment yield (1949-1954)		Post-treatment yield (1955-1960)	
			Total	Average	Total	Average	Total	Average
16	141	35	163	13·58	39	6·50	124	20·67
17	26	35	336	28·00	120	20·00	216	36·00
18	119	65	208	17·33	76	12·67	132	22·00
19	43	45	541	45·08	221	36·83	320	53·33
20	162	55	315	26·25	133	22·17	182	30·33
21	134	65	310	25·83	131	21·83	179	29·83
22	155	55	178	14·83	102	17·00	76	12·67
23	266	50	13	1·08	13	2·17	..	..
24	205	30	36	3·00	20	3·33	16	2·67
25	248	65	371	30·92	260	43·33	111	18·50
26	245	60	177	14·75	72	12·00	105	17·50
27	222	50	159	13·25	63	10·50	96	16·00
28	226	50	267	22·25	202	33·67	65	10·83
29	197	50	257	21·42	123	20·50	134	22·33
30	195	50	66	5·50	21	3·50	45	7·50
31	220	50	163	13·58	74	12·33	89	14·83
32	417	30	..	..	..	..	..	..
33	347	65	228	19·00	147	24·50	81	13·50
34	311	60	81	6·75	78	13·00	3	0·50
35	372	25	41	3·42	30	5·00	11	1·83
36	329	35	70	5·83	22	3·67	48	8·00
37	353	65	318	26·50	178	29·67	140	23·33
38	431	45	320	26·67	162	27·00	158	26·33
39	425	65	135	11·25	89	14·83	46	7·67
40	434	65	131	10·92	47	7·83	84	14·00
41	455	30	..	..	..	..	..	..
42	338	40	96	8·00	33	5·50	63	10·50
43	343	50	491	40·92	236	39·33	255	42·50
44	336	45	731	60·92	295	49·17	436	72·67
45	382	50	536	44·67	274	45·67	262	43·67
46	386	50	228	19·00	95	15·83	133	22·17
47	274	30	222	18·50	144	24·00	78	13·00
48	250	45	310	25·83	126	21·00	184	30·67
49	278	65	268	22·33	190	31·67	78	13·00
50	366	50	77	6·42	24	4·00	53	8·83
51	373	60	341	28·42	189	31·50	152	25·33
52	405	50	148	12·33	80	13·33	68	11·33
53	353	45	236	19·67	57	9·50	179	29·83
54	374	45	278	23·17	150	25·00	128	21·33
55	202	45	58	4·83	36	6·00	22	3·67
56	243	40	156	13·00	128	21·33	28	4·67
57	200	15	..	..	18	3·00	..	..
58	204	40	29	2·42	19	3·17	10	1·67
59	225	55	288	24·00	120	20·00	168	28·00
60	60	60	231	19·25	93	15·50	138	23·00
61	68	55	..	..	6	1·00	..	..
62	107	60	150	12·50	77	12·83	73	12·17
63	82	35	170	14·17	73	12·17	97	16·17
64	84	60	196	16·33	87	14·50	109	18·17
65	138	60	..	..	58	9·67	..	..
66	34	20	122	10·17	33	5·50	89	14·83
67	36	55	197	16·42	105	17·50	92	15·33
68	142	45	403	33·58	165	27·50	238	39·67
69	154	55	137	11·42	65	10·83	72	12·00
70	11	50	170	14·17	106	17·67	64	10·67

The Difference of Yield between Lefts and Rights

In each of the 6 comparisons made in Table 6 it will be seen that the mean number of nuts on the Lefts exceeds that on the Rights. This is clearly shown in Figs. 1 to 4.

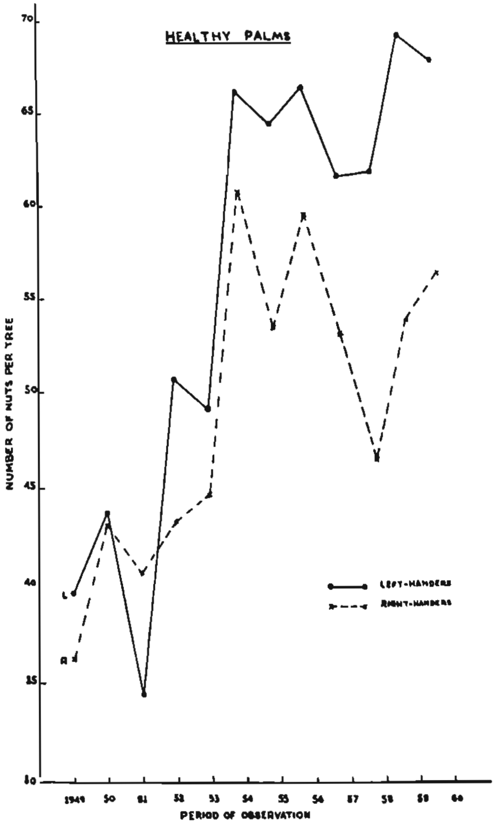

Fig. 1. Annual yields of healthy coconuts from 1949 to 1960.

The significance of these differences, as shown by the t test, is given in Table 7. The distributions of the means are near enough to normality to make the t test unobjectionable. However, it somewhat under-estimates the significance, because, as will be seen from Figs. 1 to 3, during the last period of 6 years, in which the data are most reliable, the Lefts in each group surpassed the Rights in every year. Since the yields of a given tree in successive years are highly correlated, and, as the result of alternation in some trees, those in years n and $n+2$ probably still more highly correlated, the excesses in different years are not independent. So it would be difficult to calculate how much the figure of ·0038 would be reduced if the data for each year were considered.

The data for the diseased trees are not in themselves significant, but are in the expected direction, and considerably enhance the significance of the data on the healthy trees. In fact the overall probability that the Rights produce as many or more nuts as Lefts is about ·00014, and still less if the supplementary information from the first 6 years and

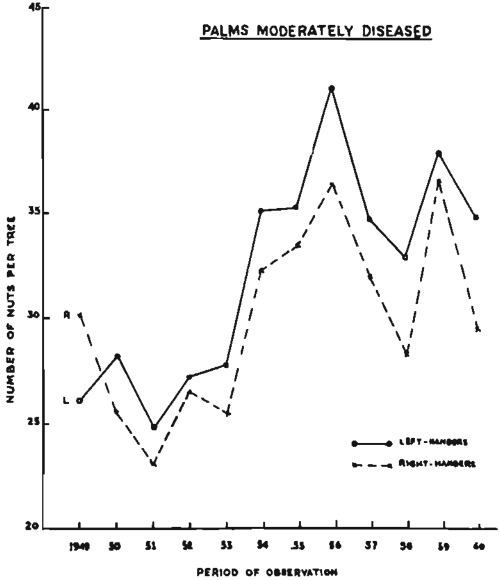

Fig. 2. Annual yields of moderately diseased coconuts from 1949 to 1960.

Table 6. *Annual yields*

Category		Number	12 years (1949-1960)		6 years (1955-1960)	
			Mean	Variance estimate	Mean	Variance estimate
Healthy	L	58	57·69	437·42	65·60	616·46
	R	70	49·82	366·74	54·28	455·17
Early diseased	L	60	32·95	292·12	36·54	323·24
	R	66	30·55	375·34	33·10	524·715
Late diseased	L	56	22·05	266·56	23·63	314·68
	R	64	20·04	186·59	20·33	239·12

Table 7. *Significance of Left-Right differences*

Comparison		d. of freedom	*t*	P
Healthy, 12 years	..	126	2·22	0·15
,, 6 years	..	126	2·77	0·0041
Early diseased 12 years	..	124	0·733	0·234
,, ,, 6 years	..	124	0·933	0·18
Late diseased 12 years	..	118	0·736	0·21
,, ,, 6 years	..	118	1·09	0·14

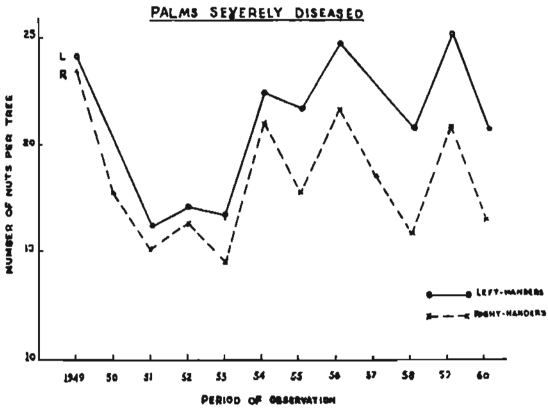

Fig. 3. Annual yields of severely diseased coconuts from 1949 to 1960.

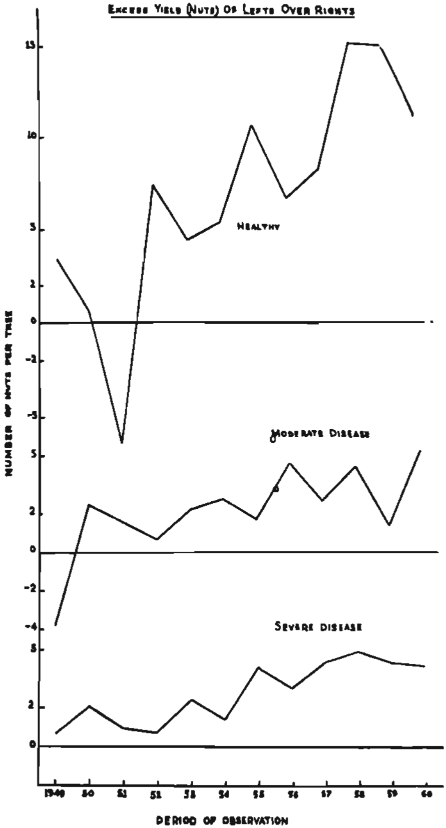

Fig. 4. Excess nut-yields of left-handed over right-handed coconuts.

from the concordance of different years is taken into consideration. Probably P would be about 10^{-8}. However there is no doubt of the significance of the result, and it is more important to show that Lefts yield more than Rights in other breeds and climates.

Fig. 5 shows the distributions of the yields of healthy Lefts and Rights from 1955 to 1960. If a population had been made up of half of each, its variance would have been 600·0, of which the difference between the means of Lefts and Rights contributes 64·07 or 10·7 percent. Among the healthy trees after treatment the Lefts gave 20·9 percent more nuts than the Rights. But it is perhaps more instructive to consider a population composed of equal numbers of Lefts and Rights. It would have a mean annual yield of 59·94 nuts. It is quite possible to cull the Rights as seedlings before transplantation. In this particular case this procedure would have increased the yield to 65·60, that is to say by 5·66 nuts per year, or 9·4 percent. This could be a considerable economic advantage. But before such a procedure can be recommended, it will be necessary to show:

(*a*) That the increased number of nuts is not offset by a diminished yield of copra.

(*b*) That the results obtained in one plantation in Kerala are also obtained elsewhere.

(*c*) That the effect is not one of the type discovered by Roy (1960), Lefts being stimulated by Rights, and Rights depressed by Lefts when they are grown in a mixture.

I hope to investigate these possibilities.

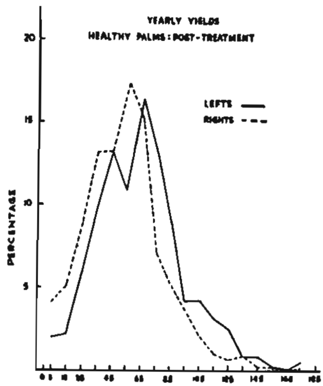

Fig. 5. Annual nut-yields of healthy coconuts (post-treatment).

DIFFERENCES IN THE LEAVES OF LEFTS AND RIGHTS

The higher nut yield of the Lefts is very probably due, at least in part, to the fact that they possess more leaves. In 1953, when micronutrients were first applied, the total numbers of green leaves were counted. Each leaf was numbered with weather proof paint, and only the numbers of fully opened leaves (that is to say those whose lowest leaflets have emerged from the clasping leaf-sheath) were included. A tree usually has about five leaves which are not fully opened but partially visible above the sheath. The date of emergence of each leaf was also recorded.

Table 8 gives means and variances of leaf numbers. For the healthy trees the mean difference is 1·60 leaves; and quite significant. This means that Lefts have on an average 5·4 percent more leaves than Rights. The differences for the diseased trees are in the same direction but not significant. Since they bear 20·9 percent more nuts, the greater number of leaves can hardly account for all of this excess.

Table 8. *Number of green leaves per palm*

Particulars	Mean		Variance		*t*	P
	Left	Right	Left	Right		
(1) Healthy palms	31·19	29·59	17·88	15·23	2·23	·014
(2) Moderately diseased ..	29·18	28·25	22·12	18·22	1·17	·12
(3) Severely diseased ..	26·16	25·40	19·85	18·88	0·97	·17

The next step is to compare the leaves. I have as yet no data on stomata or chloroplasts, however Table 9 compares 6 characters. 1583 leaves from 55 healthy trees (experimental trees), selected at random, were measured for their total length, lengths of lamina region and petiole, length and width of longest leaflet, and the number of their leaflets counted. Of these, 24 trees were Lefts. In each tree about 30 consecutive leaves were examined. As normally a tree takes a little over two years to produce 30 leaves, the data given in Table 9 may be free from any bias due to seasonal variations.

The total length of the leaf is the distance from the broadened leaf base to the tip of the central axis which usually ends with a single leaflet or is somewhat prolonged into a small whip (Venkatanarayana, 1957). The region from the leaf base to the base of the lowest leaflet is regarded as the petiole and that from the base of the lowest leaflet to the base of the topmost one forms the green leaf region or the leaflet-bearing region. This length has been obtained by subtracting the length of the petiole from the total length of the leaf. The number of leaflets is usually counted for one side. But the leaflets of both the sides are not the same in number. While making the counts, no specific side was preferred, and it is presumed that the probability of counting both sides is equal and therefore the difference between sides might not have vitiated the

Table 9. *Coconut leaf: Summary of 6 characters*

Characters	Means		$\bar{X}_1 - \bar{X}_2$	Variances		t	P
	$\bar{X}_1$	$\bar{X}_2$		S_1^2	S_2^2		
1. Total length ..	402·31 cm.	407·14 cm.	−4·83 cm.	195·3504	182·6724	6·9486	<0·001
2. Lengths of petiole	101·55 ,,	106·09 ,,	−4·54 ,,	28·4510	28·7752	16·7466	<0·001
3. Lengths of green region ..	300·76 ,,	301·05 ,,	−0·29 ,,	761·2023	1258·0989	0·1774	0·8584
4. No. of leaflets on one half ..	108·19	109·59	−1·40	19·8996	14·4354	6·7437	<0·001
5. Longest leaflet: (*i*) Length ..	108·19 cm.	106·84 cm.	+1·35 cm.	63·1031	56·9374	3·4500	<0·001
(*ii*) Width ..	5·29 ,,	5·30 ,,	−0·01 ,,	0·2672	0·3747	0·3534	0·7230

Suffix 1 denotes Lefts
Suffix 2 denotes Rights
n_1 = 693 leaves (from 24 palms)
n_2 = 890 leaves (from 31 palms)

results significantly. The length as well as width of the leaflets increase when proceeding from the lowest leaflet (nearer to leaf base) and at about the third of the leaflet-bearing region from the base, the longest and presumably the widest leaflets are met with. It is customary to measure the length and width of this leaflet for estimating the green leaf area.

Table 9 contains some leaf measurements. While the overall length of the leaf of a Right is greater than that of a Left by 4·83 cm, the length of the green leaf portion which is the vital part of the leaf, is practically the same for both the types. The difference, therefore, is brought about by the significantly longer petiole in the case of the Right. Patel (1938) considers the longer petiole to be decidedly an undesirable character since it is positively correlated with longer peduncles of inflorescence. Further, longer leaves are associated with palms living under over-crowded situations, and where there is lack of light. A leaf of a Right has 1·4 leaflets more than a Left leaf on one side and this works out to be 1·29 percent. But a Left is superior by possessing 1·26 percent more width of the longest leaflet. Thus, the green leaf area of a leaf of the Left may be regarded as equivalent to that of its counterpart. Therefore the excess 1·6 leaves per palm of the Left gives a significantly larger area than the Right. Normally this should contribute to some extent to the production of the extra number of nuts.

The extra number of leaves of the Lefts normally should enhance the number of their bunches, although a greater number of bunches need not necessarily denote a greater number of nuts. The numbers of leaves shed by all the healthy and diseased (experimental) palms during the 12 months in 1958 are given in Table 10. Among the healthy group, the Lefts and Rights had shed the same number of leaves. As there is a positive correlation between the leaves shed and leaves produced in coconut, it may be presumed that the rate of production of leaves in the Lefts and Rights is the same when once the stage possessing the normal numbers of leaves is reached. This may therefore mean that the leaves of the Lefts remain green on the crown for a longer period.

Table 10. *Number of leaves shed during 1958*

Particulars	Left-handers			Right-handers		
	mean	max	min	mean	max	min
Healthy palms	13·59	17	11	13·58	16	9
Moderately diseased	13·23	16	7	13·23	17	9
Severely diseased	12·65	16	10	12·36	16	7

New Genetical Data

Besides the data (Davis, 1962a) for trees both of whose parents are known, I give data on 308 seedlings from 5 mothers in a large nursery, sown in 1960 and examined in 1961. The pollen parents are of course unknown, but presumably were about equal numbers of Lefts and Rights. Table 11 shows no significant heredity. The 3 Left seed parents gave 78 L, 75 R, the 2 Rights gave 72 L, 83 R, $\chi^2_1=0{\cdot}632$, so the slight tendency to resemble the seed parent is quite insignificant.

However in view of our ignorance it is worth while to enquire whether there is any evidence of somatic segregation within bunches. The values of χ^2 for heterogeneity for the 5 trees are:

$\chi^2_2=2{\cdot}262$ $\chi^2_3=3{\cdot}058$ $\chi^2_7=5{\cdot}411$

$\chi^2_4=2{\cdot}097$ $\chi^2_3=0{\cdot}302$

totalling $\chi^2_{18}=13{\cdot}13$, $P=\cdot 78$. It is possible that further work might show a significant tendency to equality within bunches. There is no suggestion of segregation between bunches.

Table 12 gives data on asexual reproduction in exceptional palms scattered over most of the coconut-producing area of India and observed by myself since 1960. Double shoots in a coconut are possible due to at least three causes. In a fruit only one seed usually develops, the other two aborting at an early stage. But in exceptional cases where two seeds remain fertile, two shoots (one from each seed) are possible from a fruit. Even in the case of fruits with only one developed seed, two or more shoots are possible due to polyembryony. Further, when the single shoot branches at an early stage, two shoots from a fruit are possible, and this phenomenon is called suckering. I have also mechanically divided the single shoots in two nuts inducing two

Table 11. *Leaf spirals of progeny obtained by open pollination*

Seed parent and its spiral		Bunch No.	Spiral of progeny L	Spiral of progeny R	% lefts
1	L	1	nil	1	
		2	4	5	
		3	8	4	
Total for the tree		3	12	10	54·55
2	L	1	10	5	
		2	9	9	
		3	1	4	
		4	15	20	
Total for the tree		4	35	38	47·95
3	R	1	2	nil	
		2	3	4	
		3	10	6	
		4	2	4	
		5	1	nil	
		6	1	2	
		7	4	4	
		8	6	8	
Total for the tree		8	29	28	50·88
4	R	1	6	6	
		2	8	15	
		3	5	8	
		4	14	12	
		5	10	14	
Total for the tree		5	43	55	43·88
5	L	1	10	7	
		2	12	12	
		3	9	8	
Total for the tree		3	31	27	53·45
Grand total for 5 trees		23	150	158	48·70

Table 12. *Double shoots, Branching and Suckering*

		L	R	total shoots	L—R
Double shoots:	20 twins	1	1	40	—
	7 „	2	0	14	+14
	6 „	0	2	12	−12
Branching	2 trees	1	2	6	−2
	2 trees	2	1	6	+2
	1 tree	3	0	3	+3
	1 tree	0	4	4	−4
	3 trees	3	2	15	+3
	1 tree	3	3	6	—
	1 tree	4	2	6	+2
	1 tree	2	5	7	−3
"Bulbil shoots", mother L		16	4	20	+12
Total	46	77	62	139	+15
Tall selfed (mother L)		16	16	32	
spicata (B. 7) L × Tall (B. 4) R		14	11	25	
Tall (B. 4) R × *spicata* (B. 7) L		6	6	12	

shoots in each case (Davis, 1960). I have studied the direction of leaf spiral in 33 such double shoots. Of these, twenty shoots had one left and the other right. But in seven others, both the shoots had left spirals while in six others both were rights. On a random basis, for 33 pairs of twins, the position will be,

Spiral	Observed	Expected
LL	7	8·25
LR	20	16·5
RR	6	8·25

There is a slight excess of unlike pairs, but this is not significant. $\chi^2_{1c}=1{\cdot}09$.

I also give the spiral directions of the various shoots of branching and suckering palms examined by me. The shoots per palm ranged from three to seven. However, I have observed coconut palms with as many as 27 shoots, but their leaf spirals could not be examined. For the sets of 3, the following is the situation,

Spiral	Observed	Expected
LLL	1	0·625
LLR	2	1·875
LRR	2	1·875
RRR	0	0·625

Similarly for the sets of 4, 5, 6 and 7 the orders can be tabulated. There is no indication of the character being inherited. I consider that in a palm with more than one shoot, even if one shoot shows a different leaf spiral, it suggests the non-genetical nature of the character. Since these are the vegetative shoots, they can be layered (Davis, 1961b) and propagated into individuals. In this case one could get clones with different spirals. However, another phenomenon occurs in the coconut where the flower bunches instead of developing into spadices revert to vegetative shoots, occurrence of which has been recorded by many. In one such tree where the mother was a Left, I found 16 of the "progeny" out of 20 behaving like the mother. Thus the bulbil-shoots have a strong resemblance to the "mother", $\chi_{1c}^2=6{\cdot}05$. More accurately, the probability of getting 16 or more out of 20 resembling the parent is $6{,}196\times 2^{-20}$, or 0·00591. So it is fairly sure that there is real resemblance. But I feel it may be hasty to come to conclusions from a single case. I propose examining more of such abnormal palms.

Self-pollination also can be effected artificially in the tall variety, since the viability of the pollen can be easily retained for over a week under normal desiccation, within which period the female phase of the same spadix is sure to commence. Of course, retaining the viability of the pollen is no longer a problem, since under deep-freezing, pollen remains viable even for a year. At the Agricultural Research Station at Nileshwar, Kerala, there are progenies obtained by controlled self-pollination. Second generations of these palms are also being obtained by further self-pollination. Out of the 16 progeny I examined at Nileshwar of a tree subjected to self-pollination, exactly half the number possessed a left spiral. *Cocos nucifera* var. *spicata* is peculiar in that its spadix remains unbranched and also bears a greater number of female flowers than males (Jacob, 1941). When this was crossed with an ordinary tall (B 4) having different leaf spirals, out of 25 progeny, 14 were Lefts. And when tall (B 4) was crossed with the *spicata*, exactly half the progeny were Lefts.

Among palms, *Hyphaene thebaica*, *H. coriacea* and *H. indica* have the normal capacity to branch. There is a controversy with regard to their mode of branching. According to some it is dichotomous branching, while others consider the buds to be axillary. I am inclined to believe the latter view. This can perhaps be better understood if the branching which is rather common in *Chrysalidocarpus lutescens*, a suckering palm, is traced. Recently I observed the branches of a few palms of *Hyphaene thebaica* growing at the Botanical Garden, Howrah, and noted that the leaf spiral in different branches differed. There is also no order of this irregularity.

Having enough data to prove that the leaf asymmetry in the coconut is non-inherited, I made an attempt to see whether the direction of leaf spirals could be changed by artificial means. I started mechanically dividing the growing points of young seedlings. In a seedling having a left spiral, when the division was effected, growth continued through only one half, and this subsequent shoot had a right spiral. While many shoots behaved like this, in some, the same direction was maintained. These shoots were again and again divided till most of them died. Thus I saw that during some divisions, the direction of spiral in the subsequent shoot changed, while in others it did not. I may further mention that the leaf spirals of the different shoots of the two twins I have induced artificially are of opposite directions. It is more interesting that one of the dwarf (green) palms at the Indian Statistical Institute, Calcutta has on its stem clear indication of change of the leaf spiral from left to right at a point about 0·7 m above ground level and where a prominent abnormal swelling is visible which I believe is the result of severe mechanical injury.

Frequency of Lefts and Rights

I had earlier reported my observation on 3028 palms gathered from eight small regions in Calcutta, Madras and Kerala. The Lefts accounted for 52·05 percent, and some peculiarity was observed between the smaller groups. The difference of the totals was significant (P=·020) by the usual criterion. This would not be so if the ratios in the different groups were significantly heterogeneous. But χ^2 as a test of homogeneity was not very high in spite of one exceptional population. So I decided to observe a large number of trees (over 10,000) firstly, to establish the existence of the excess of Lefts with higher probability, secondly to establish whether exceptional populations are common, and thirdly to detect regional or racial differences, if they exist.

Data given in Table 13 are about the tall variety of coconut collected personally by myself from five of the coconut growing states at centres mentioned below; West Bengal: Calcutta, Howrah and 24-Parganas; Orissa: Cuttack, Sakhigopal and Puri; Andhra Pradesh: Anakapalle, Visakhapatnam and Waltair; Madras: Madras city, Madurai, Kanyakumari and Nagercoil; Kerala: Kayangulam, Ernakulam, Kozhikode, Nileshwar and Kasaragod; and Mysore: Mangalore. The palms observed include bearing and non-bearing palms and even young seedlings. I consider my observations to be fairly accurate, since I am familiar with alternative methods of determining the leaf spiral if I met with doubt by one method. Out of the total of 11,688 palms examined, 51·214 percent are Lefts. Though the Lefts are in excess, it may be mentioned that this figure is slightly less than what I got earlier on a much smaller population. The sub-figures are almost evenly distributed except that for Andhra where the Lefts are 56·583 percent. However, χ_1^2 on the total is 47·78 and hence P is less than 10^{-7}.

I also arranged to collect similar data (on the tall variety) from a few more centres in India, and the data are presented in Table 14. The workers to whom the requests

Table 13. *Distribution of Lefts and Rights in India (Data collected by author)*

Place		Lefts	Rights	L+R	L−R
1. West Bengal ..	..	867	829	1696	+38
2. Orissa ..	..	712	734	1446	−22
3. Andhra Pradesh	..	679	521	1200	+158
4. North Madras ..	..	672	695	1367	−23
5. Central Madras ..	..	522	513	1035	+9
6. South Madras ..	..	537	507	1044	+30
7. South Kerala ..	..	523	504	1027	+19
8. Central Kerala ..	..	474	493	967	−19
9. North Kerala ..	..	793	703	1496	+90
10. Mysore ..	..	207	203	410	+4
Total	..	5986	5702	11688	+284

were made to observe the leaf-spirals are familiar with the crop, and clear instructions were given as to the method of making the observation. Out of 3,768 palms thus examined, the Lefts form 51·778 percent. In six out of seven centres, it was the Lefts that were in excess though in small degrees. Thus when the Indian figures are pooled (Tables 13 and 14) we get 51·352 percent of the 14,956 palms as Lefts and an excess of Lefts in 13 out of 17 populations.

Table 14. *Distribution of Lefts and Rights in India (Data obtained through others)*

Place		Lefts	Rights	L+R	L−R
1. Assam: Karimganj	..	254	252	506	+2
2. Madras: Kanyakumari	..	311	303	614	+8
3. Kerala: Neyyattinkara	..	189	231	420	−42
4. „ Kayangulam	..	421	358	779	+63
„ Kumarakom	..	215	185	400	+30
5. Maharashtra: Ratnagiri	...	259	241	500	+18
6. Gujarat: Bhavnagar	..	302	247	549	+55
Total	..	1951	1817	3768	+134

Leaf Data from Abroad

Since the distribution of the two types of palms in India has been observed to be almost in equal proportions, I was interested to see how the palms in the rest of the world behave with regard to this leaf character. The coconut is distributed almost throughout the tropics, and the main regions according to Leo Schnurmacher (1938) are: Malayan Archipelago, consisting of the Philippines, Netherlands-Indies (now Indonesia), Sarawak, Papua, New Guinea, Timor and Gambing; South East Asia comprising Malaya, Siam and Indochina; India and Ceylon; Pacific Territories (Gilbert and Ellice Islands, Nauru, Mariana, Caroline and Marshall Islands, Solomon Is., New Hebrides, New Caledonia, Fiji, Samoa, Tonga and Cook Is., French Oceania and Guam); East Africa and neighbouring states such as Mozambique, Madagascar, Tanganyika, Kenya, Zanzibar, Seychelles and Mauritius; West Africa, chiefly Gold Coast, Nigeria, Dahomey, Guinea, Togoland, Angola etc.; West Indies consisting of Trinidad, Tobago, Jamaica, Grenada, St. Vincent, Virgin Islands, Puerto Rico, St. Lucia and St. Kitts; Central and South America such as Mexico, Br. Guiana, Panama, Honduras, Columbia and Surinam.

Research organisations are not so far set up in all the above-mentioned countries or regions. But I am in contact with about 40 organisations covering most of the major coconut producing countries. I am glad that over 75 percent of the organisations responded to my request favourably by furnishing me with the data asked for by actual counts. In a few countries, the information was obtained through more than one agency. I took care to furnish detailed procedures including sketches to these agencies in order to collect uniform data, and I am satisfied that with a single exception (Br. Honduras), my explanation proved clear enough to be followed without confusion.

I have given in Table 15 the figures received from the various countries and those obtained from India, and they are arranged geographically starting from Tonga Islands in the Pacific Ocean, going westward via Indian Ocean, Africa, Atlantic Ocean and the Americas. The sums of the Lefts and Rights are almost equal. Of these figures, the ones received from Andaman Islands are very peculiar, since the Lefts are only 37·35 percent. When I requested more data from a different locality, the subsequent figures also showed the same peculiarity with a slightly increased intensity. Thus the world totals give 50·48% Lefts without the Andamans, which percentage is reduced to 49·71 when the figures for Andamans are considered. However, the frequencies of Lefts and Rights in all the countries (from which data has been obtained) is almost one half in each case, in spite of this character being non-inherited. On the other hand the total American figure is 57·18% Lefts. But that for British Guiana is 63·51% which is as aberrant as the Andamans Sample. A glance at the columns showing the differences of Lefts and Rights in Table 15 will show that a slight excess of Rights is perceivable for countries starting from Tonga Islands roughly up to Ceylon. But beyond this, the Lefts are on the increase and the intensity goes on increasing as we proceed towards America. The gradual drift in the proportion of the Lefts and Rights with distance (longitudinally) is unexpected and an explanation perhaps is

Table 15. *Distribution of Lefts and Rights. World totals.*

Country	Lefts	Rights	L+R	L−R
1. Tonga Is.	234	266	500	−32
2. American Samoa	516	484	1000	+32
3. Western Samoa	96	104	200	−8
4. Fiji	223	277	500	−54
5. New Hebrides	265	235	500	+30
6. New Caledonia	216	334	550	−118
7. Br. Solomon Is. Protectorate	1461	1621	3082	−160
8. Trust Territory of Pacific Is.	247	275	522	−28
9. Papua and New Guinea ..	406	398	804	+8
10. Netherlands New Guinea ..	414	586	1000	−172
11. Philippines	726	774	1500	−48
12. North Borneo	244	332	576	−88
13. Sarawak	275	325	600	−50
14. South Vietnam	1833	1478	3311	+355
15. Malaya	272	228	500	+44
16. Andaman Is. (India) ..	903	1597	2500	−694
17. Assam (India)	254	252	506	+2
18. East Pakistan	499	586	1085	−87
19. Ceylon	1803	1754	3557	+49
20. India: Bengal, Orissa, Andhra	2258	2084	4342	+174
21. „ Madras	2042	2018	4060	+24
22. „ Kerala	2875	2722	5597	+153
23. „ Mysore, Gujarat & Maharashtra ..	768	691	1459	+77
24. Mauritius	15	19	34	−4
25. Zanzibar	244	216	460	+28
26. Nigeria	222	278	500	−56
27. Dahomey	520	510	1030	+10
28. Ghana	568	557	1125	+11
29. Ivory Coast	505	554	1059	−49
30. Sierra Leone	784	749	1533	+35
31. Surinam	475	335	810	+140
32. Br. Guiana	416	239	655	+177
33. Jamaica	467	443	910	+24
Total ..	23046	23321	46367	−275

worth trying for. Though I do not deny the possibility of slight inaccuracies in the figures received from abroad I do not think that this gradual change with distance is due to any inaccurate observation.

THE DWARF AND OTHER "VARIETIES"

There are only two main varieties of coconut, the tall and the dwarf, although an intermediate is also noticed in some localities (the King coconut in Ceylon, Gangabondam in Andhra, India). The tall variety is characterised by its prodigious height, longevity up to about one hundred years and regular bearing habits. It takes about seven years to commence flowering and is a highly cross-pollinated variety. The dwarf variety on the other hand starts bearing by the third year of planting and largely breeds true to type, since self pollination is possible. It grows to only half the height of the tall, and dies by about the sixtieth year. Cultivation of this variety on a large scale is not preferred on account of its poor copra.

I have given in Table 16 data relating to the leaf spirals of the dwarf variety, the semi-dwarf (serial numbers 8 and 9) and a few other "varieties". The Lefts on the total of 1265 palms account only for 47·83 percent. When only the dwarf palms are considered (numbers 1 to 7), the Lefts are slightly less, 47·21 percent. Of the seven centres, five have excess Rights, one Left and the seventh is almost neutral. Of the two American figures, while Jamaica has 54·74 percent Lefts, Surinam has 54·68 percent Rights and this do not seem to be in conformity with the figures for the tall variety. From the table given below, it is fairly clear that the dwarfs have an excess of Rights. The progenies between the tall and the dwarf show almost a non-aligned position. But this being a single case comprising a smaller number of seedlings it may be regarded as a chance occurrence.

Table 16. *Dwarf and other "varieties" of coconut (Distribution of Lefts and Rights)*

Place		Lefts	Rights	L+R	L−R
1. Dwarf : Jamaica	..	104	86	190	+18
2. Dwarf : Trust Territory of Pacific Is.	..	16	20	36	−4
3. Dwarf : Zanzibar	..	15	25	40	−10
4. Dwarf : Surinam	..	218	263	481	−45
5. Dwarf : India, Kayangulam	..	72	71	143	+1
6. Dwarf : India, Kasaragod	..	31	41	72	−10
7. Dwarf : India, Calcutta & Madras		34	42	76	−8
8. King Coconut ..	..	8	13	21	−5
9. Gangabondam ..	..	14	18	32	−4
10. Tall × Dwarf cross	..	54	53	107	+1
11. Var. *spicata* ..	..	3	1	4	+2
12. Tall × *spicata* ..	..	6	6	12	—
13. Other exotic races	..	30	21	51	+9
Total	..	605	660	1265	−55

DISCUSSION

Further data confirm that the direction of the leaf spiral is not inherited. One can also add with some assurance that it is not genetically determined. For there are cases of genetical determination without heredity, for example sex in human beings and many animals, and heterostylism in plants where illegitimate pollinations are completely sterile. The data of Tables 11 and 12 also suggest that it is not due to extra-nuclear segregation. I am investigating asymmetry in other plant species, and this may suggest reasons why Lefts and Rights occur in nearly equal numbers. I also hope to discuss the world distribution more fully.

The slight excess of Lefts in most populations could be explained as follows, if a young seedling had exactly equal probabilities of being a Left or a Right. The Lefts have more leaves and a larger leaf area. This may enable them to resist diseases and pests better, and if the most vigorous seedlings are selected, Lefts may be preferentially chosen. Both natural and artificial selections may operate.

I hope later to correlate other characters with the direction of the foliar spirals. These include girth of stem and height at given ages, the number of leaves in seedlings, the yield of toddy or sweet sap from inflorescences and possibly the hydrostatic pressure developed by the roots, which can exceed 12 metres of water (Davis, 1961a). From the economic point of view the annual yield of copra and its oil content are still more important.

A number of scientific colleagues have been kind enough to write to me as to my results. Professor R. D. Preston, F.R.S. writes "The connection between the yield of coconut palms and the tilt of the conducting tissue is very intriguing indeed and is so unexpected as to be on the verge of the credible. Since the sign of the spiral is not inherited then one is compelled to assume that the orientation of the conducting tissue affects the disposal of the materials being conducted and I know of no mechanism which would incline me *a priori* to have believed such a phenomenon". The fibres in a coconut stem are arranged somewhat spirally, the twist corresponding to that of the leaf spirals. Petch (1911) was among the first to report this. This applies to the fibres on the outer stele, but inner layers may tend to twist in the reverse direction. I have not so far succeeded in observing the presence or absence of a spiral organization either in the cell surfaces or the cytoplasm. The late Sir Ronald A. Fisher, F.R.S. was kind enough to examine my numerical data and to satisfy himself of their statistical significance. He wrote "He (Davis) is mistaken if he thinks that I think that he has nearly completed the elucidation of a very queer situation". Professor Haldane, F.R.S. makes the following suggestion. "The larger molecules of which palms are built, and in particular the cellulose fibres, are asymmetrical, and often arranged in spirals. But the direction of the foliar spiral may be a matter of "chance", that is to say determined by causes unconnected with the molecular asymmetry. The asymmetrical molecules may however fit more readily onto the growing tissues of trees with left-handed spirals." Dr. R. C. Snow, F.R.S. is also of opinion that the arrangement of leaves at an early stage may depend entirely on external causes.

I describe below some fantastic results on beans reported by the astrophysicist, Grote Reber (1960) which are comparable with the results on coconuts. Nine different kinds of pole beans (Hawaiian bean whose Linnaean name was not mentioned) were planted in rows of about fifty hills each. All nine kinds twined about in the same direction as a right-handed screw thread. The vines on even numbered poles of three rows were carefully unwound and twined backwards. The runner was loosely tied about two inches below the tip, and this process was repeated whenever the runner had grown eight to ten inches. All vines and pods were allowed to ripen, wither and dry on the poles and subsequently harvested. The field data on each hill consist of number and weight of pods, number and weight of beans, weight of shucks, number and weight of vines. In all cases there is an appreciably better ratio of ounces of beans/ounces of shucks, and to a lesser extent ounces of beans/ounces of vines for the reversed vines compared to the normal vines. Apparently this training of the vines causes an increase in ratio of fruit to supporting structure. The same experiment was performed in a qualitative way both on Maui, Hawaii and Kempton, Tasmania, Australia, with similar results. The reversed vines gave somewhat better production of green beans in these cases. It was reported that the vine turned the same way in both the northern and southern hemispheres.

Dr. Snow raised a doubt whether the extra number of nuts may not be due to the mistake of the person who harvests them, "since the bunches hang to the kathodic side of each leaf, it is easier for a right-handed man to cut them off in a left-spiralled tree, and he tends to miss some bunches in the right-spiralled". But the answer is simple. Even if a few ripe nuts remain uncut they will be accounted for either as shed nuts or during the subsequent harvest. The nuts of a tree are accounted for for a continuous period of 12 years, and the trees are harvested eight times in the year.

So far I have not weighed the copra of the two types of trees. Only if the increase in the number of nuts is proportionately seen in the weight of copra, can the superiority of the Lefts be regarded as valuable. My yield data relate to a small locality in Kerala and I do not claim that this will be the situation elsewhere.

Higher yields both of nuts and copra, though in a smaller degree, have since been observed in Ceylon.

Summary

Further data confirm that the direction of leaf spirals in *Cocos nucifera* is non-inherited. In all probability it is also not genetically determined.

Fresh data on the frequency of Lefts and Rights from India as well as 27 other countries are reported. A slight excess of Lefts is noticed in most populations, but on the totals, the two groups do not differ significantly. However, in the case of a few countries, abnormal figures were received which show significant differences between the Lefts and Rights.

The Lefts give 20·9 percent excess yield of nuts over their counterpart, although it is based on a non-inherited character, and that is quite inexplicable. Among diseased

palms also the difference is in the positive direction, but not significant by itself. The number of the leaves of the Lefts is slightly greater, and this may account, in part, for the increased yield of nuts of the Lefts. It is not known whether the increase in the number of nuts of the Lefts is associated with a proportionate increase in the weight of copra.

Acknowledgement

A portion of the data presented in this paper relates to another experiment I was conducting at the Central Coconut Research Station, Kayangulam, Kerala (India). I am grateful to the Indian Central Coconut Committee for the same. Help received from Dr. K. P. V. Menon, Director, Coconut Research, Kayangulam, and several junior colleagues for collecting the data is gratefully acknowledged. I am obliged to the Joint Director, Coconut Research, Kasaragod and the Superintendent, Agricultural Research Station, Nileshwar, with whose cooperation I could gather most of the information contained in Tables 11, 12 & 16. I am specially thankful to the various foreign and Indian colleagues who supplied me very promptly with the valuable data on the frequencies presented in Tables 14-16. But for Professor J. B. S. Haldane, F.R.S., I would not have realised the full significance of the present finding. He is also responsible for the statistical treatment of most of the data.

REFERENCES

Davis, T. A. (1960). Clonal propagation in coconuts. *Curr. Sci.*, **29**, 273.

Davis, T. A. (1961a). High root-pressures in palms. *Nature*, **192**, 277-278.

Davis, T. A. (1961b). Importance des racines aériennes du cocotier. *Oléagineux*, **16**, 653-661.

Davis, T. A. (1962a). The non-inheritance of asymmetry in *Cocos nucifera*. *J. Genet.*, **58**, 42-50.

Davis, T. A. (1962b). Asymmetry and yield in coconut. *Experientia*, **18** (7), 321-322.

Jacob, K. C. (1941). A new variety of coconut palm (*Cocos nucifera* L. var. *spicata* K. C. Jacob). *J. Bombay Nat. Hist. Soc.*, **41**, 906-907.

Leo Schnurmacher, Inc. (1938). *Review of coconut products for 1938, Manila.*

Patel, J. S. (1938). *The coconut—a monograph.* Govt. Press, Madras.

Petch, T. (1911). Right and left-handed coconut trees. *Ann. Royal Bot. Gard. Peradeniya*, **5**, 538-539.

Reber, G. (1960). Reversed bean vines. *Castanea*, **25**, 122-124.

Roy, S. K. (1960). Interaction between rice varieties. *J. Genet.*, **57**, 137-152.

Venkatanarayana, G. (1957). On certain aspects of the development of the leaf of *Cocos nucifera* L. *Phytomor.*, **7**, 297-305.