The Possibility of Afforesting Soils of the Old Red Sandstone in Ireland*

By Walter Wittich.

The soils of the Old Red Sandstone formation of the Devonian period are widely distributed in the south and south-west of Ireland. As they are, practically speaking, unproductive, their afforestation has been under consideration for many years. It is an open question whether it could be carried out by means which would be economically justified or whether it would be possible at all. After many unsuccessful experiments it seems generally agreed that the soils in their present state are quite unsuited for afforestation and that some fundamental improvement would be necessary. What form this improvement should take is disputed. In my opinion, success is conditional on an accurate knowledge of the character of the area and of the nature of the " soil sickness ". Only when one has a clear knowledge of the physical, chemical and biological peculiarities of the soils can one hope to discover the measures adapted to the area and to avoid costly mistakes. These suggestions aim at making some small contribution to the problem. Thanks to the kindness of the Director of the Forest Service, Mr. Reinhardt, I was able to study soils of the Old Red Sandstone formation in various parts of Ireland. The places where afforestation had already been attempted were particularly interesting. It was possible here to trace the connection between the development of different species and the soil properties and thus to come nearer to the causes of failure. A particularly suitable example of this sort is found on the Ballyhoura Hills in the south of Ireland, and the following study is concerned with this example. The shortness of my visit forced me to confine myself to a study of superficial soil conditions. I took and studied more closely samples from one typical profile.

The afforested area lies on a gentle southern slope of the Ballyhoura Hills. The parent material of the soil is a diluvial glacial debris, consisting of material of Old Red Sandstone, laid down as a thick layer on the unweathered rock of the same formation. Afforestation was carried out over a large area during the years 1910-15† and experiments with different kinds of soil treatment were carried out at the same time. *Pinus sylvestris* was the main species planted; apart from a few weakly plants it has disappeared. Oddly enough, *Pinus contorta* shows better growth although there is no difference in soil conditions. Unlike the Old Red Sandstone formation in England, which is, for the most part, of maritime origin and rich in minerals, the formation in Ireland is an inland lake deposit, consisting mainly of quartz and containing few bases and little weatherable material. There is, in particular, a great deficiency of

* Translated from " Intersylva," No. 3, 1942, and published by kind permission of the author and of the editors of " Interslyva."—Editor.

†This should read " 1924-28."—Editor.

lime. Vegetation adapted to these conditions is naturally equally deficient in bases, so that the decomposition of dead plant material, in the damp Irish climate with its cool summers, took an unfavourable course from the first. The result was the formation of a thick humus or peat bed, which must be several decimetres in depth, and which, as " mountain or heath peat ", covers vast areas of the Irish mountains. In the afforested area the peat had been used as fuel for many years and to-day the bare soil is visible.

Under the influence of the acid peat layer and the humid climate, podzolization was bound to make rapid progress in this poorly-buffered material. The result is that to-day we find an extreme example of the podzol profile. The leached horizon (A) consists of slightly loamy sand and reaches to a depth of about 25 cm. Sample No. 1 was taken from here. The next, severely compacted horizon (A/B), reaches an average depth of 40 cm., in many places even deeper (Sample 2); it is, as one can see from its superficial appearance, much richer in the finer articles. This is clearly due to the fact that the particles leached from above are mechanically prevented from further downward penetration by the underlying iron hard-pan (Sample No. 3), and thus accumulate above it. The hard-pan, 7-10 cm. thick, is unusually compact. It has the effect of armour plate, completely shutting off the upper horizons from the subsoil. Sample No. 4 was taken from a depth of 90 cm. It is true that this horizon (B/C) shows clearly influences from the upper horizons, but as a result of the sealing-off by the hardpan, such influences are very restricted, so that in many respects this horizon is similar to the unweathered parent material and can for some purposes be regarded as identical with it.

TABLE 1. PARTICLE SIZE, MINIMUM WATER CAPACITY AND pH

No	Horizon	Particle size of the fine soil				Minimum water capacity p.c.	pH	
		2-0.2 p.c. " Coarse Sand"	0.2-0.02 p.c "Fine Sand"	0.02-0.002 p.c. "Silt"	Less than 0.002mm p.c. "Clay"		KC1	H2O
1	A	32.94	56.56	8.24	2.26	10.6	3.4	3.9
2	A/B	32.30	44.49	13.20	10.01	16.7	3.9	5.1
3	B (Ironpan)	24.84	55.21	12.75	7.20	13.7	3.9	5.3
4	B/C	28.03	46.15	11.62	14.20	14.6	3.9	5.3

Table 1 shows the composition by particle size of the fine soil, i.e., of the fractions under 2 mm. in size. The soil contains a considerable amount of coarser material, and of fair-sized stones. The results of the mechanical analysis confirmed what one could see clearly enough with the naked eye, the poverty of the A horizon in raw clay and, to a lesser extent, in silt. This is not solely a question of a mechanical displacement, but, as we shall see later, also of the "sol" type of leaching of clay decomposition products, under the influence of humic acids. The mechanically transported particles of clay and silt have accumulated above the hardpan, filling up the spaces, while the highly hydrated organic colloids, brought down by leaching at the same time, have destroyed the cohesion between the mineral particles and led to extreme compaction. The minimum water capacity is, as shown by the last column but one of Table 1, much higher in this horizon, as a result of the accumulation of clay particles, than in horizon A. Practically speaking, this is of no great importance, since the movement of water is determined rather by the impermeability of horizon B.

Research on the biological condition of the soil was not possible, because the samples dried out too much during transport. There can be no doubt, however, that it is unfavourable in every respect. The hydrogen-ion concentration is high (Table 1). All the samples lacked nitrate. Apart from small quantities of ammonia, the nitrogen occurred in a bound form in organic compounds. To make it available to plants, it would be necessary to increase the biological activity of the soil, and, as an essential condition for this, to effect a thorough-going reduction in soil acidity.

TABLE 2. CHEMICAL COMPOSITION

No	Horizon and depth in metres	CaO p.c.	MgO p.c.	K2 O p.c.	Na2O p.c.	P2O5 p.c.	Fe2O3 p.c.	Al2O3 p.c.	SiO2 p.c.	N p.c.
	Ballyhoura Hills									
1	A	—	0.03	0.05	0.04	0.008	0.05	0.17	0.71	0.04
2	A/B	0.005	0.09	0.16	0.08	0.01	0.21	1.46	1.74	0.03
3	B(Ortstein)	—	0.12	0.13	0.07	0.02	2.45	1.28	1.79	0.02
4	B/C	0.004	0.09	0.19	0.09	0.02	1.39	1.49	1.80	0.01
	Eberswalde subdistrict 20									
5	1 m	0.03	0.04	0.03	0.04	0.01				
6	2 m	0.05	0.01	0.02	0.06	0.01				
7	3 m	0.03	0.04	0.02	0.04	0.01				
	Carzig subdistrict 140									
8	1 m	0.08	0.04	0.04	0.11	0.03				
9	2 m	0.50	0.02	0.04	0.10	0.03				
10	3 m	0.54	0.02	0.04	0.10	0.04				

Table 2 shows the results of chemical analysis (extraction with concentrated hydrochloric acid). In comparison with the B/C horizon (No. 4), we find that the A horizon is very poor in all nutrients. Calcium, magnesium, potassium and sodium are present in the next horizon in approximately the same amounts as in the subsoil; this horizon is deficient in iron, and, to a less extent, in phosphorus. The hardpan has naturally a higher content of iron, but in respect of the other nutrients differs very little from the subsoil.

In order to appraise the nutrient status of the Irish soils, we shall compare them with two typical diluvial sands from Brandenburg. The first (Subdistrict 20, Eberswalde forest) belongs low down in the 3rd; the second (Subdistr. 140, Carzig forest) in the 2nd quality class. The Eberswalde soil has, in a fine sand content of 65 per cent., 97 per cent. quartz. The soil is, indeed, slightly podzolized, but there is no question of any pan formation in the B horizon sufficient to affect the growth of the roots to the slightest extent. Compared with this soil, the Irish soil is decidedly deficient in calcium; on the other hand, it is richer in potassium and magnesium. In the B/C horizon, we find 1/10 of the calcium of the Eberswalde soil but eight times the potassium, three times the magnesium and twice the sodium and phosphorus. Taking Ca, Mg and K together, the Irish soil is three times as rich in these important bases as that of Eberswalde. Compared with the fertile Carzig sand, the Irish soil has four times the potassium and three times the magnesium content. On the other hand, the Carzig soil is somewhat richer in phosphorous, and much richer in calcium.

When one considers that the relatively poor Eberswalde area gives satisfactory forest yields, it is evidently necessary to revise the usual assumption that only the low nutrient content of the Old Red Sandstone prevents the cultivation of trees. This is confirmed by the fact that, where the lower horizons have been exposed, as in the gullies (to be discussed later), caused by sudden strong erosion, the few Pines, which have come in by chance, have developed normally although conditions in this raw soil are unfavourable in themselves. It is not that the parent rock is too poor in plant foods, but that it is too poor, in the climatic conditions prevailing there, to offer sufficient resistance to extreme podzolization. In Brandenburg, where the climate is of a continental character and there is half the rainfall, the continual splitting off of bases from the Old Red Sandstone would have been enough to counteract severe soil degradation. A slightly podzolized soil, providing, nevertheless, quite adequate conditions for plant growth, would have developed. With a slightly higher calcium content, we might have expected the development of a brown forest soil, as in the case of the second of the soils used for comparison. Here the continual supply of bases split off from the silicates is sufficient to prevent the breakdown of clay and the displacement of the products of decomposition, instead of which a *de novo* formation of clay substance occurs. As weathering acts most strongly at the surface, we find that the proportion of clay decreases with depth. The content of silt and clay is four times as great in the A horizon as in the lower part of the B horizon. In the Irish soil, the distribution is reversed. In the extremely damp climate of Ireland, with its mild winters and cool summers, severe decomposition of the clay and a sol type of leaching of the decomposition products into the subsoil occurs. This is clearly shown by the distribution of the inorganic colloids in the soil, quantitively determined by Tamm's method—extraction with ammonium oxalate (Table 3).

TABLE 3. INORGANIC COLLOIDS

No.	Horizon	SiO_2 p.c.	Fe_2O_3 p.c.	Al_2O_3
1	A	0.47	—	0.13
2	A/B	1.71	—	0.29
3	B	2.96	0.72	0.30
4	B/C	3.45	0.12	0.17

In the A horizon we find an abnormally low colloid content. All the colloidal iron has been leached out. Not even a trace is left. It is still missing in the horizon immediately above the hardpan, but has accumulated heavily in the latter. An important fact in the development of the soil condition is that the iron has been precipitated in a comparatively narrow horizon, causing the formation of the compact hardpan, which has intercepted the particles washed down and become a serious obstacle to drainage of water. The aluminium hydroxide colloids have been leached only from the A horizon, and there only in part. They accumulated not only in the hardpan but in the horizon above (No. 2), which is in this case a horizon of accumulation, but, in the case of iron, one of extreme leaching. The distribution of colloidal silicic acid is again quite different. It increases evenly with depth, and the greatest quantity is found below the hardpan (No. 4). This B/C horizon must, therefore, be considered as a horizon of accumulation for silicic acid. Obviously the hardpan is no obstacle to the colloidal silicic acid, which, as an electro-negative sol, can pass even through fine capillaries. It is present in considerably larger quantities than the iron and aluminium colloids in all horizons.

To sumarise, we can establish that the soil has suffered unusually severe destructive processes. The A horizon has almost entirely lost its active sorption complexes, while in the Carzig sand taken for comparison, the upper horizon is particularly rich in both organic and inorganic sorption complexes. The poverty of the Irish soils in sorption complexes is shown by the quantity of exchangeable ions available in the different horizons, which can be determined either by exchange with salts, or, as in the present case, by ultra-filtration. Only magnesium, which does not pass through the collodion filter, had to be determined by exchange with ammonium chloride. Besides the ions that are held by the sorption complexes proper, others from the crystal lattice are also exchanged. However, it is only in the subsoil that these play an important part in comparison with the first group. Table 4 shows the results. We see that the lowest horizon has considerably more exchangeable bases than the impoverished topsoil. In a healthy soil the position is reversed. It is also noticeable that the alkalis considerably preponderate over the calcium, while, generally, as in the case of the soils taken for comparison, the calcium ions greatly exceed the alkali ions. The amount of exchangeable magnesium cannot be directly compared with the bases of the ultrafiltrate, because the methods are not comparable. Its values are, however, unusually high—about 10 times those obtained by the same method from the diluvial sands already mentioned. The pronounced calcium deficiency and the relative richness in Mg and K, as shown by the chemical analysis, are thus reflected in the ions held by the sorption complexes. The phosphoric acid is probably present in the form of iron and aluminium phosphates. There were hardly any phosphate ions present in the ultrafiltrate.

TABLE 4. RESULTS OF THE ULTRAFILTRATION

	Ultrafiltration						Exchange with
Minutes	Anions	Cations	Ca	K+Na	NH3	P2O5	NH4Cl mg
	m.e.	m.e.	m.e.	m.e.	m.e.	m.e.	m.e.
			A Horizon				
0—20	0.192	0.168	0.039	0.077	0.04	0.010	
20—50	0.060	0.044	0.020	0.016	—	0.006	
0—50	0.252	0.212	0.059	0.093	0.04	0.016	0.165
			B/C Horizon				
0—20	0.134	0.472	0.063	0.195	0.05	—	
20—50	0.035	0.050	0.029	0.010	—	—	
0—50	0.169	0.522	0.092	0.205	0.05	—	0.200

m.e.: milli equivalent

The nutrition conditions apparent from an investigation of the distribution of the sorption complexes and the nature and quantity of the ions held, a knowledge of which is important for the determination of the remedial measures to be taken, are very unfavourable. By themselves, however, they cannot account for so complete a failure of the Pine plantations. The physical characteristics of these degraded soils are far more decisive. We remember that the silt and raw clay particles washed down from above, accumulated above the hardpan. As a result of poverty in electrolytes and the effect of the acid humus materials, there is no cohesion between these particles. Each time the soil becomes waterlogged it takes on a pasty consistency in which the newly-formed pores disappear again. The soil " flows together ", thus becoming extremely compact. Cultivation is useless, unless the fundamental evil is removed; the artificial structure of the soil thus obtained disappears again at the first heavy rain. This compacted layer itself becomes relatively impermeable and increases the sealing effect of the hardpan. The result is periodic waterlogging after heavy rainfall. On the slopes, an unusual and characteristic phenomenon occurs. During the frequent torrential rainstorms common in Ireland, the water which is unable to penetrate into the soil flows downhill with such force that, under certain topographical conditions, erosion gullies are formed in some places. The water rushes into them from all sides, and runs through them with such violence that it can even erode away the armour plate of the hardpan. When this obstacle is removed, the water rapidly scoops the bed down to a considerable depth. The afforestation area on the Ballyhoura Hills is thus crossed by many erosion gullies, which are said to cut their way one metre deep into the soil within a few days and are deepened to 3 metres by later downpours of rain. In the Old Red Sandstone area of Clonmel, I even found an erosion trench which was 8 metres deep. These erosion phenomena occur only where the peat has been cut for use.

The severe compaction of the soil and the periodical waterlogging cause the Pines to develop unusually shallow roots. Even plants which have survived so far confine their rooting to the upper 5-10 cm. It is understandable that plants confined to this shallow layer, exposed to all the changes of weather, grow weakly and finally die. It is noteworthy that the roots of *Pinus contorta*, the species that shows satisfactory growth in these conditions, penetrate deeper and sometimes even reach down to the hardpan. It is known that the common Pine is particularly sensitive to oxygen deficiency, while other species stand it better. *P. contorta* appears to be one of these species. According to investigations by Forbes, *P. montana* and, in some areas, *P. laricio* also show satisfactory growth in such conditions.

Once we are clear about the nature of the " soil sickness ", it is not difficult, at least theoretically, to suggest measures for its cure. First and foremost, the soil must regain its permeability to water, and be opened up for the passage of roots through to the subsoil. For this the hardpan must be removed, and a normal structure restored to the horizon above it. The latter can be done by mixing together the soil from the eluvial and illuvial horizons, so providing for the reconstitution of base-saturated sorption complexes, as has been done with strongly podzolized soils in Denmark, and more recently in Holland and N.W. Germany. The material, rich in colloids, of the B horizon is mixed by ploughing with that of the A horizon. This is followed by heavy dressing with mineral fertilizers, above all with lime, so that base-saturated sorption complexes are formed. This lime dressing at the same time brings about an improvement in the biological conditions of the soil, and an activation of the humus. By this means the soil regains normal physical and chemical properties, particularly structure, permeability to water, and base-exchange capacity. At the same time, through the removal of the hardpan, the lower soil layers are made available for root growth. In this way it was found possible in Denmark to bring back into a high level of productivity extremely podzolized soils, which had resisted all attempts at afforestation. Theoretically, it would be possible to do the same with the soils of the Ballyhoura Hills, but not in practice. The technical difficulties are too great In general, the hardpan lies too deep to be broken up by the plough. Moreover, the large number of stones would make mechanical cultivation difficult. It would, on the other hand, be pointless to use methods of cultivation which did not remove the fundamental evil. Just to break through the hardpan would not be enough, because it would soon form into a hard layer again.

A second possibility is to abandon the idea of opening the lower horizons to the roots, and instead to bring about optimum conditions in the layers above the hardpan. This seems feasible where the thick peat has not been removed and the hardpan lies very deep. The peat consists largely of lignin and lignin fractions, which are released by the breakdown of the readily-decomposed associated carbohydrates. After liming, they undergo strong autoxidation. This forms acid groups, of great importance to the soil's sorption capacity; and, through polymerisation, combination into valuable true humus material is effected. A necessary condition is that nitrogen should be added to the soil in quantity, in order that during this polymerisation it may be incorporated into the newly-formed humus molecule in the form of " nuclear " nitrogen. Even in an atmosphere of strong biological activity, these true humus materials are extremely resistant to bacterial attack, especially when they are linked to clay particles. Clay of the montmorillonite type contained in many kinds of marl is particularly valuable. With this very active clay substance, an admixture of only about 2 per cent. is enough to produce effective linkage, and thus a high degree of stability in the humus. These newly-formed true humus materials possess a great sorption capacity, have a favourable physical effect and, after application of mineral fertilizers, can create excellent conditions for plant growth. Where this converted peat is mixed with the mineral soil by cultivation, the structure of the latter is also improved. Its capacity for absorbing water is increased so much that quite heavy rainfall can be absorbed without waterlogging. In spite of the limited rooting space, a fertile soil can be created in this way. For the time being such improvement may, perhaps, seem too expensive for forest use; it is, however, worth considering even to-day for conversion of land to agricultural use.

On the Old Red Sandstone in the neighbourhood of Clonmel, I found, besides the deep erosion gullies already mentioned, slight sheet erosion of the upper soil layers on rather steeply sloping ground. The presence here of tree stumps, in contrast with neighbouring areas where this erosion was not present and the profile was the typical one already described, showed that a stand must have existed there; and judging from the size of the stumps it cannot, at least, have been of poor growth. I do not know if such eroded slopes exist on any considerable scale in the Old Red Sandstone area. Where they do occur they could, I think, be afforested without any particular treatment, though dressing with lime would, no doubt, be desirable.

It is impossible to say for certain whether afforestation of the degraded soils with such unexacting species as *Pinus contorta* would be worth-while without preliminary treatment. The early growth of this species is satisfactory, it is true, but I doubt wheher the older stand, with its greater need for rooting space, would find conditions adequate for survival.

I also found soil conditions similar to those described in the Old Red Sandstone of Clonmel. Attempts at afforestation had failed here, too. It would, however, be quite wrong to judge all soils of the Old Red Sandstone on the same basis. The parent material is not sufficiently uniform for that. The contents of material susceptible to weathering, and of bases, vary within certain limits, and with them so does the resistance of the soil to destructive processes. It is true that we find strong podzolization everywhere, but not in so extreme a form as on the Ballyhoura Hills. I have seen soils in which I should expect the roots to find their way through to the B/C horizon. In my opinion, afforestation should, therefore, be possible, provided, of course, that the site had a suitable climate and is not too exposed to the effect of westerly gales, a point which must always be watched in Ireland.

The examples dealt with here show how necessary an examination of the soil is for all afforestation. This applies not only to the Old Red Sandstone area, but to many other site types, found in such extraordinary variety in Ireland. Examination of the soil is necessary in the first place to ascertain which areas are to be excluded as unsuitble for afforestation. Further, it should throw light on the peculiarities of the soil to be afforested, so that improvement and planting measures can be adapted to the particular local conditions. Soil research will make it possible considerably to reduce failures in the afforestation which is being carried out so vigorously by the Irish State.