

The contributions of Frederick Hardy to tropical soil science and soil survey

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ABSTRACT

Frederick (Fred) Hardy (1889–1977) entered the field of soil science before it was fully considered an independent academic discipline and was influential in establishing an early understanding of the interactions between ecology, agriculture, and soils. He achieved this through his recognition that emphasis needed to be placed on what farmers were presently growing, which would then lead to valuable insights with regard to the soil parameters vital to the crop. These insights came from his recognition that field studies, including talking to farmers, provided valuable information on the parameters vital for crop growth. The Caribbean region, in which Hardy worked, was well suited to these ideas given the rapid changes in geology, topography, and land use across the islands. Building on this, Hardy therefore believed that soil surveys were an important facet in any understanding of agricultural production.

This approach was until recently, a reversal of the wider thinking where little attention was paid to the intrinsic knowledge of the farmers. Hardy's ideas were supported by extensive research, and field experience in soil survey. This informed his lengthy and far-reaching teaching career, and shaped the training of many colonial agricultural officers, agronomists, and soil scientists and placed him as one of the leading figures in tropical soil science in the first half of the 20th Century. His achievements can be compared with those of Geoffrey Milne and his colleagues in East Africa and C. F. Charter in Ghana, though Milne's most significant work was undertaken in the 1930's while Charter's work was two decades later (Borden, et al., 2019; Young, 2007). We review Hardy's career in the Caribbean and discuss his influence on methods of survey, classification of tropical soils, and his teaching and institutional building contribution.

1. Introduction

Frederick (Fred) Hardy travelled to Barbados in 1911 to take up a post at the Imperial Department of Agriculture College and worked extensively in the Caribbean region until his death in Trinidad during 1977. Thus, his background in the study of tropical soils is derived from his long experience of field work across the islands of the Caribbean. This legacy is clear from his extensive publication record, which is grounded in time spent in the field, recording soil observations in relation to crop performance: this was informed by talking with farmers and growers. These soil observations were in line with the drive at this time to increase primary production from the tropical regions, with an emphasis on export crops such as cocoa. In the Caribbean the scale of production was both at commercial level with added inputs from small holders. Therefore, field work brought the soil surveyors into contact with smaller farmers and plantation managers.

Hardy based his understandings on soil survey which he related to

soil conditions and crop performance and was very aware of changing environmental conditions across the islands and the influence of parent material, slope, drainage, land use, and climate on soil morphology. These insights were timely as soil science was emerging as a distinct discipline and the multifaceted nature of soil formation was being recognised during the 1930s. The Caribbean region was important as the soil forming factors altered markedly across a small distance unlike more uniform tracts of land in tropical Africa for example. These ideas of multiple influences on soils were later codified by Jenny (1941). The distinctive contribution made by Hardy to this debate was his emphasis on field studies and especially soil survey, which became recognised by the commercial producers of export crops such as sugar cane and cocoa.

It is also important to recognize the legacy of Fred Hardy through his teaching of generations of students in the Caribbean and elsewhere. His early academic career brought him into contact with agricultural officers who were posted across the then Empire. In the Caribbean region his detailed field observations became an essential start point for any

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future soil studies, providing a foundation for soil surveys in many of the islands.

In this paper we review Hardy's career in the Caribbean and discuss his influence on the classification of tropical soils, his methods of survey, and his role in teaching and research.

2. A Caribbean career

With a Cambridge Natural Sciences Tripos (Geology, Botany and Chemistry), in 1911 Fred Hardy joined the Imperial Department of Agriculture' Harrison College in Barbados, teaching Natural and Agricultural Science. In 1917 he returned to England as a chemist in a munitions factory until 1919 when he joined the Ministry of Agriculture's Land Reclamation Branch team undertaking a soil survey of the north coastal belt of the Wash. (Peterhouse 1921). This was one of the earliest soil surveys conducted in England. It is likely that in 1918 Hardy was planning to return to the West Indies and thus decided to better prepare himself by joining this soil survey in Lincolnshire in preparation for returning to Cambridge in 1920, to obtain a Diploma in Agriculture. On completion of this, he returned to the West Indies to the position of Agricultural Chemist in the Imperial Department of Agriculture (IDA). He was posted to Antigua but soon left to join the newly formed West Indian Agriculture College (WIAC) when it was established in Barbados in 1921. The College then moved to Trinidad and became the Imperial College of Tropical Agriculture (ICTA) where Hardy became the Professor of Soil Science and Chemistry heading up both departments, a position he retained until he retired in 1955. He then joined the Inter-American Institute for Agricultural Sciences at Turrialba, Costa Rica as Professor of Soil Science, becoming, if he was not already, the leading authority on the natural environment for the successful production of cacao. In 1960 ICTA became in 1960 the Agriculture Faculty of the University of the West Indies (UWI), allowing Hardy to return in 1966 as Professor Emeritus, where he continued to be involved in the activities of the faculty until his death on 9th April 1977.

3. Hardy and the evolution of soil science

The context for the work of Fred Hardy is that during the 1920s an understanding of soils was gradually broadening from the early dominance of, first soil chemistry, and later geology which emphasised the importance soil parent material. This close relationship with geology rested on the input of early geologists who were confident field workers and had the ability to understand soils in the context of local sites. The unique environments in the Caribbean with rapid changes in climate, soil parent material, topography, and land use all occurring in relatively confined island geography, led Hardy to an early understanding of the interplay of the many environmental factors in soil formation. By 1936, Hardy had grasped these ideas which he clearly summarised in a special volume of Tropical Agriculture (Hardy, 1936).

"It is evident from this summary of some of the main findings of these studies that a very wide range of problems is presented to the scientific investigator of the soils of the West India region. The soil-forming rocks include almost every main type known to the geologist. Every stage of agricultural development is represented, ranging from forest exploitation, shifting cultivation and peasant settlement to estate organisation, orchard management and intensive gardening. Numerous different kinds of tropical and sub-tropical crops are grown, both herbaceous and arboreal, and many different systems of cultivation are practised, involving hand tillage, implemental tillage, thorough drainage, irrigation, cover cropping and all sorts of manuring. The value of exact field experimentation is gradually being realised, and the need of detailed soil surveys is becoming increasingly experienced as economic conditions and external competition is forcing the agriculturist to learn how to conserve soil fertility, to improve yields, and to diminish costs of production."

An early influence on Hardy was his experience in soil survey in

England when he spent some time during 1918 with a soil survey unit in the Wash area of Lincolnshire. It was not until 1937 that England adopted a more nuanced approach to soil classification similar to that used in the USA. While Hardy had adopted the British approach, he was aware of the work of other soil survey pioneers and the evolving approaches to soil mapping. In his study of 'The Soils of Jamaica', he mentions: '*certain soil types defined by Russian and American pedologists*' to develop a method of identifying the soil characteristics that affected agricultural production (Hardy, 1933, Hardy and Croucher, 1933). Furthermore, he notes that field survey "*provided valuable information concerning the climatic and soil requirements of two important tropical crops, banana and sugarcane, which has since been employed in attempts to assess and evaluate other soils planted to these crops in other parts of the West-Indies region*".

As has been noted the imperative driving forward the Hardy interest in soil studies was improved primary production of export crops. Hence an early publication by Hardy reported on work on cocoa on the island of Tobago. These pioneering studies linking soils and agronomy and investing in soil mapping became a fundamental of all the Hardy work in the islands including the study of more cocoa soils in Grenada, and sugar cane in Antigua. Hardy built on this experience by always returning to his fundamental idea that detailed observation and a recognition that on-farm cropping patterns was integral to understanding of soils, and that soil survey was the appropriate tool to clarify these relationships. Hardy added an additional dimension to this approach by feedback from both commercial managers and smaller farmers who work at different commercial scales. This moved the understanding of tropical soils forward, by allowing relevant local knowledge to be valued and to become part of any field study.

4. Research and publications

Hardy was convinced that since soil forms the basis of all agricultural production:

"the accumulation of such relevant data as can be obtained by reliable methods of field and laboratory research thus requires no justification, and the start that has already been made in the study of west Indian soils which should lead the way to their fuller understanding" (Hardy, 1936).

This understanding of the importance of surveys is clear, as between 1921 and 1935, during breaks in the academic year, Hardy undertook and published 10 soil surveys and then in 1947 three more, all published as the series 'Studies of West Indian Soils I-XIII - generally referred to as the, 'Grey Books'. These surveys covered 11 islands in the Lesser Antilles plus Jamaica and British Honduras (Belize). Most of these soil survey reports and subsequent further research publications were co-authored by Hardy and his colleagues, particularly G. Rodriguez (who oversaw the laboratory analysis) and/or graduate students (Hardy, 1936). The Dominica and Montserrat soil surveys and at least eight related research papers were published before 1927 when the British Colonial Department of Agriculture acknowledged the potential value of soil surveys. At the Imperial Agricultural Research Congress in London a resolution was passed to strengthen agricultural research through inter-territorial cooperation in the organisation of soil surveys (Ministry of Agriculture and Fisheries, 1928).

Hardy was not alone in recognising the link between the information that a soil survey provided and agricultural production; at least two other Agricultural Chemists in the Colonial Service Arthur Hornby in Nyasaland (Malawi), and Frederik Martin in Sierra Leone had also commenced soil surveys before 1927 (Young, 2007).

At the time, the early soil surveyors in England and Scotland tended to take the geological formation as the basis of their work, assuming that each formation would give rise to a soil type which could be characterised (Hall and Russell, 1911), Hollis and Avery (1977) and Hallett and Deeks (2012); Hardy therefore adopted the same approach. It was not until 1937 that England adopted a zonal system, similar to that used in the USA.

Hardy would have been aware of the work of others though his personal contacts and as a member of the International Union of Soil Scientists. Many of these were mainly general-purpose surveys focused broadly, in contrast to Hardy's specific purpose approach. An exception was the Dutch soil surveyor O. Arrhenius in Java who had identified acidity as the main soil factor affecting sugar cane yields as had Francis Watts and his Agriculture Chemist colleagues in the West Indies and who thus developed a method similar to that of Hardy (Leake, 1930; Young, 2007). Like Hardy, soil scientists in Canada at the time recognised the importance of the soil drainage characteristics within areas of similar parent material (Hallett and Deeks, 2012). F. A. Wyatt who commenced a soil survey of Alberta in 1921 believed that the first stage in identifying causes of land management problems, and thence to mitigate them, was to determine what soil features were most important and to map their landscape variability (Leskiw et al., 2020).

Hardy's summary of the results of these studies of the soils of the West Indian region was that a wide range of factors impacted on agricultural production. This was particularly evident given the wide variation in climate, geology, and stages of agricultural development across the region, therefore the utility of detailed soil surveys. It was becoming increasingly clear that an important component in learning how to conserve soil fertility, improve yields, and diminish costs of production rested on basic soils information.

5. Soil survey and methodology

The 'Hardy method' was focused on crop-soil relations. He viewed the study of soils at the time showed: *"too great a tendency to discuss the potentialities of soils in terms of their laboratory analyses alone, and that little, if any, reference was made to their geological, topographical and ecological relationship in the field"* (Hardy, 1921b).

In all his early reports he describes the geology, the chief physical properties of the soil profiles in the area, and the main soil types, with the intention of forming a basis for future guidance to those investigation soil and agronomic problems. In this regard these reports are similar to H. A. Tempany's, 1915 report on the Soils of Antigua (Tempany, 1915) and the emphasis on the parent material in early soil mapping in England (op. cit., 2012).

A report of the 1950 Soils Conference held in Puerto Rico, recorded that the soil classification systems so far used in the British islands had been mostly petrological as opposed to the pedological systems used elsewhere in the West Indies (Caribbean Commission, 1950). Drainage had been used in classifying the soils of Trinidad and Tobago and British Honduras. The exception to this was in Antigua where C. F. Charter's soil survey (Charter, 1937) was based on G. W. Robinson's modification of the English system to include soil series and suites, which was more like the system developing in American survey procedures at the time (Hardy, 1949; Borden et al., 2021).

Hardy began each of his soil surveys by first locating where a particular crop grew best and where it did not thrive. Thus, his approach to soil survey was a reverse of that practiced elsewhere at that time. His starting point was to use the crop grown to indicate the suitability of the soils of a specific area for the crop before identifying soil characteristics and therefore land suitability. Since in most cases the crops of the West Indies were perennial, this information was easy to obtain. While there is no evidence of systematic recording of yields, his contact with smaller farmers ensured that he incorporated the knowledge of the landowner in the survey. Once he had this information, he would dig pits in the selected areas to identify the relevant soil characteristics including drainage and collect samples for analysis. Thus, the agricultural performance of the soils, with respect to a specific crop, as indicated by the farmer/land manager was associated with the soil characteristics from the outset (op. cit., 2007).

Hardy's first two soil surveys, Soils of Dominica (1921a) and Soils of Montserrat (Hardy, 1922) were conducted in response to specific edaphic concerns. In Dominica, the survey was based mainly on

geological considerations and involved a study of soil acidity and its role in soil fertility and possible bearing on the growth of the cacao and liming of crops. In Montserrat he investigated the relationship of the soils to the problem of lime tree die-back. While the soil properties were examined, the main purpose was essentially a study in crop ecology. In the introduction to his Montserrat soil survey report, Hardy wrote:

"During April of 1921, the writer assisted in a reconnaissance undertaken by the plant pathologist of the Imperial Department of Agriculture of the condition of the chief lime plantations of Montserrat. In this investigation, the ecological relationship between the soil conditions and the growth of lime trees was especially considered. It became evident during the course of the work that a preliminary discussion of the main features of the soils of Montserrat might be of service in future detailed research into the already much-studied problem of die-back in lime trees, as well as connexion with general questions of crop growth in Montserrat".

Further surveys were delayed by the organisation of the college chemistry department and limited laboratory facilities. At this time, he was also intent on the preparation of teaching courses. However, preliminary work on soils of cacao and forest lands in Trinidad and Tobago later provided material and laboratory data for the dissertations of several Post Graduate chemistry students (Hardy, 1936). The Cacao Soils of Tobago: Studies in West Indian Soils, Vol VIII was commenced in 1928 and published in February 1931. This involved the first two Post Graduate students (C. G. Akhurst and G. Griffith) and was the first of a new series of Caribbean reports. The general arrangement, scope and method of presentation of field and laboratory data (somewhat novel at the time) were retained unchanged in succeeding articles and reports on the Soils of the West Indies (Hardy, 1936). Table 1 shows the level of laboratory information Hardy could include in his early soil survey reports, while Table 2 shows the detail he was able to include in his later surveys.

The laboratory at ICTA was not set up when Hardy embarked on his early surveys and he therefore included existing information available from the office of the West Indies Department of Agriculture where Hardy had briefly worked. Therefore, he was familiar with this data and aware that various physical and chemical factors influence crop production (Watts, 1903). As shown in Table 1, early surveys combined geological descriptions with data such as pH linking soil properties to fertility concerns. Later when the new laboratory at ICTA was functioning his reports provide the physical and chemical information – an example of which is shown in Table 2.

Hardy did not include soil maps in his early soil survey reports, only adding a sketch map of the island surveyed. However, in his later reports, he did provide a provisional soil map. Fig. 1 of Montserrat indicates the main soil types developed on geological parent material and following a petrological rather than a pedological system (Cramer, 1950).

6. Conclusion

Hardy's contribution to the evolution of soil studies in the 1930s is rooted in his extensive and detailed work throughout the Caribbean region between 1921 and 1955. This is well supported by the substantial body of research undertaken and published, both alone and with colleagues, which amounted during his lifetime, to over 300 articles, bulletins, books and reviews. His legacy therefore is: firstly, in establishing the importance of field observation, primarily soil survey, accompanied by communication with land managers and farmers; secondly, by establishing a substantive record of applied research in soils and land use across the Caribbean region; and finally the influence the Hardy in teaching and the building of academic institutions in the region cannot be under estimated.

Consistently throughout these publications Hardy continued to emphasise the role played by environmental factors on soil morphology and edaphic factors directly influenced crop production. His work initially was directly tied to export crops and was based on soil survey

Table 1

Summary of the Soils of the Leeward Coastal Belt (Table III) (Hardy, 1921a).

Soil	District <i>b) Valley soils</i>	Description of Soil	Rainfall in inches	Hydrogen-ion concn.; pH values	Percentage of calcium carbonates	Deficiency or excess of easily sol. Base (Comber's test)
VI	Clarke Hall	Black silty alluvial soil	100	6.4	0.030	Deficiency
IV	Roseau, Bath	Sandy soil on rocky flat near river	80	6.5	–	Slight deficiency
XXI	Soufriere	Sandy black soil on stony flat land	78	6.6	0.063	Neither
V	Roseau, Bath near Emsall	Sandy black soil on stony land at base of valley cliff	80	6.7	0.080	Excess
VII	Clarke Hall	Black clayey alluvial soil with clay subsoil at 24 in.	100	6.7	0.0043	Neither
XIV	Canefield (Cacao bottom)	Sandy soil on recent alluvium	74	6.8	0.023	Slight deficiency
XVII	Picard	Silty black soil with yellowish clay subsoil at 24"	90	6.9	0.053	Slight deficiency
C	Botanic Station Cacao plots	Sandy soil with gravelly subsoil	78	7.0	0.081	Neither
VIII	Hillsboro'	Deep black soil of excellent tilth	78	7.3	0.117	Considerable excess
VIII	Canefield	Sandy soil on old alluvial flat, stoney subsoil	74	7.9	0.160	Considerable excess

Table 2

A Section of St. Vincent Laboratory Data (Hardy et al., 1934b).

	Lower depth (ins.)	Gra-vel %	Course sand %	Fine sand %	Silt + Clay %	Nor-mal (pH)	O.M. %	N. %	C/N Ratio	Avail. Nutr.	Rate of Soln.
(1) MT. BENTINCK ESTATE											
(1) Field 8, Mt. Bentinck. Canes: no arrowroot grown. Yield, 25–30 t.a. plant canes. Rainfall, 110 ins Flat land. Area covered by volcanic ash in 1902 eruption. Recent Volcanic Ash soil-type											
VNT. 1. Black	3	2	79	13	8	6.3	1.20	0.10	6.0	61	41
2. Grey-Black	6	29	76	14	10	6.5	0.60	0.06	6.3	54	33
3. Yellow-Brown	10.5	8	43	35	22	6.5	0.30	0.02	8.6	52	19
4. Black, loose	18	26	83	10	7	5.7	1.14	0.08	8.6	281	7
5. Similar	26	20	81	14	5	6.3	1.63	0.09	11.0	61	21
6. Brownish	20	55	85	8	7	6.2	–	0.01	–	60	17
7. Dark Brown	48	67	–	–	–	6.8	–	–	–	–	–
8. Similar	60	–	–	–	–	–	–	–	–	–	–
9. Paler	72	41	86	9	5	6.9	–	–	–	64	27
Phosphate: Top 6 ins. 96 ppm Potash: Top 6 ins. 145 ppm											
(1) MT. BENTINCK ESTATE											
(2) Field 1, Langley Park Canes: Yield, 35 t.a. plants. Guinea grass patch. Near Rabaka Dry River within area of 1902 ash. Flat land due N. of last. Recent Volcanic Ash soil-type											
VNT. 10. Black, loose	3	28	71	21	8	6.4	1.62	0.09	10.3	71	22
11. Similar	6	28	70	21	9	6.1	0.78	0.05	9.3	62	24
12. Black, stony	10	34	72	18	10	6.2	0.31	0.02	10.4	43	12
13 Clay-pan	14	24	50	32	18	56.3	1.55	0.04	8.3	60	16
14. Loose, black	17	–	–	–	–	–	–	0.10	–	–	–
15. Grey gravel	24	55	85	10	5	6.6	1.12	0.05	13.8	45	16
16. Black sand	36	25	93	4	3	6.6	1.31	0.07	10.8	59	22
17. Brown sand	48	15	80	11	9	6.7	0.58	0.03	10.2	42	17
18. Bright brown	60	21	68	17	15	6.6	0.47	0.03	10.0	68	25
19. Ginger brown	73	22	89	6	5	6.3	0.19	0.01	8.8	53	16
Phosphate: Top 6 ins. 77 ppm Potash: Top 6 ins. 76 ppm Second Top 6 ins. 121 ppm											

observations and field observation across the Caribbean islands. This region with variable geology, rapid changes in topography, a mixed agriculture including plantation and subsistence agriculture, together with differing climatic zones, provided an ideal environment for the study of soils in the field.

At this time soil studies were maturing into a consolidate science which moved the research onward from being formerly an adjunct to established disciplines in geology or chemistry. Later scientists such as Jenny codified these ideas in a number of 'soil forming factors', which included climate, topography, parent material vegetation, and past land use (Jenny, 1994). This, along with the wider academic recognition of his contribution to the understanding of the impact of soil characteristics

on plantation crops, particularly cocoa, ensures that Fred Hardy remains recognised as an important figure in the history of soil studies.

Tropical soil studies had made significant advances in Africa during the early 20th century based on the extensive field observations by pioneers such as Milne in Tanzania, and Charter in Ghana. Both had invested in substantial soil survey efforts across large areas. Hardy carried on this field-based approach in the Caribbean and in addition explored the linkages between his field observations and commercial crops. By taking note of crop performance, he therefore strengthened the role of soil survey in any understanding of soil and land suitability for specific crops in the tropics. This approach was reinforced by the important role Hardy played in training future Agricultural Officers who

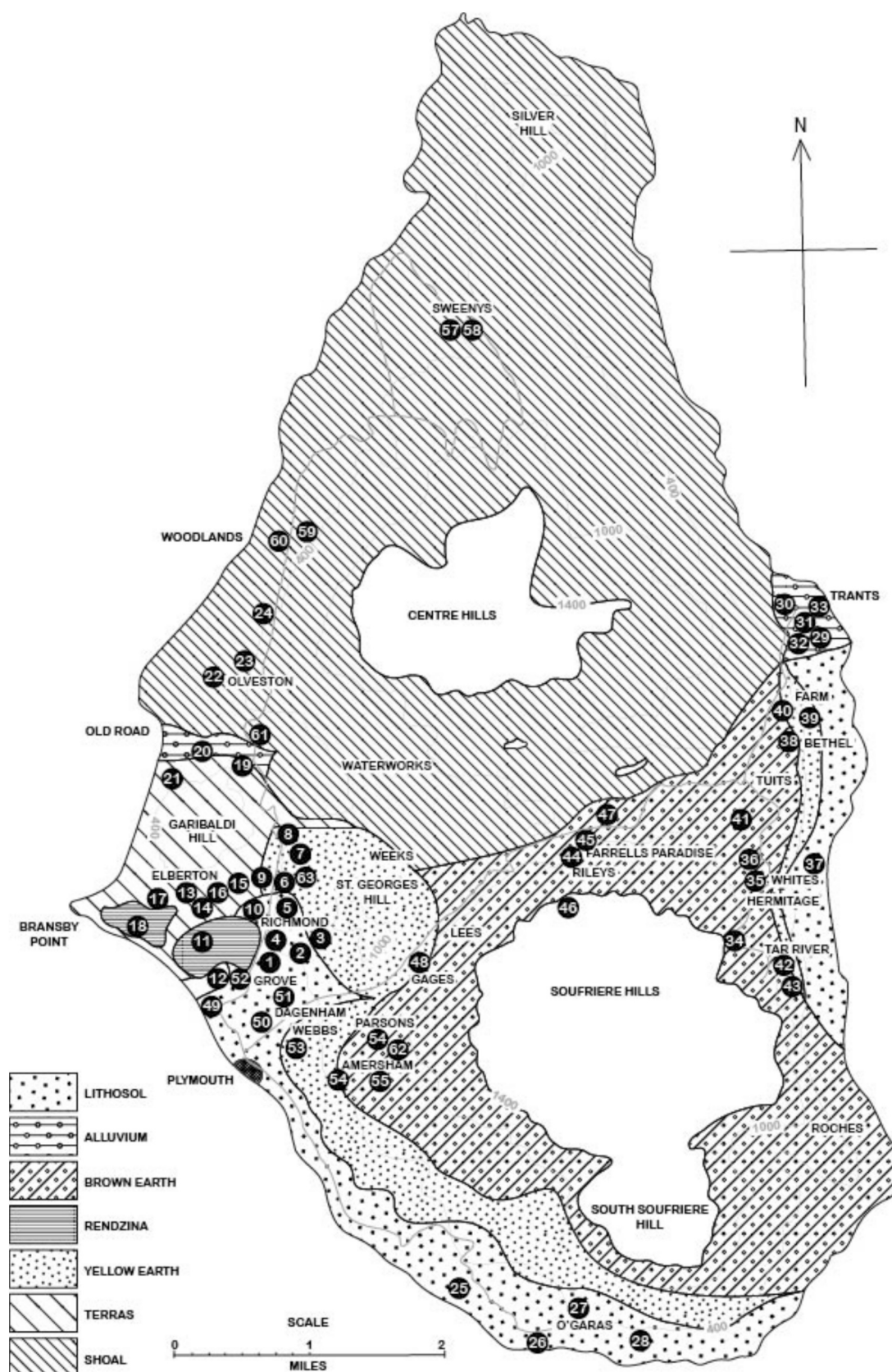


Fig. 1. Sketch Map of Monserrat redrawn by authors from original. (Hardy et al., 1949).

went on to be posted to positions in Africa.

This paper was inspired by the substantive body of Hardy documentation held by the World Soil Survey Archive (WOSSAC) at Cranfield University, UK (<https://www.wossac.com>). A recent review of this collection highlighted the breath and scope of the work carried out by Hardy and his colleagues in the first half of the 20th century. The collection of specific papers exploring specific crops and locations is matched by numerous overview papers which are regional in scope. This pioneer research has provided successive researchers with benchmark material which is fundamental to more recent research.

Impressive as this is, his contribution also had a further important dimension. For over 50 years he passed on his knowledge to a substantial number of diploma, degree and postgraduate students that he taught and supervised. These individuals went on to be leaders in the development of agriculture throughout the tropics. The actual number is difficult, if not impossible, to calculate for in addition to the 420 Colonial Agricultural Service (CAS) recruits there are those sponsored by other organisations (Masefield, 1972). In addition, Hardy influenced other ICTA, UWI and IIAS students plus those academics he met or otherwise communicated with. What is known is that his sphere of influence was both substantial and international.

The fact that very few of those students are still available today to testify makes it difficult to assess his overall influence. However, to try to obtain a deeper understanding, we have been able to contact a few colleagues who attended Hardy's lectures, post 1966. The following three comments give a flavour of his lasting influence: i) *"Hardy's lectures were excellent because of his vast field work. One of his favourite tenets 'root room' has had a major influence in my professional life. I think that if he were with us today, he would be very happy with the Conservation Agriculture movement"*; ii) *"I enjoyed Fred's class and remember him once saying to us that 'learning to name plants in the forest was not helpful. What is important is to understand the interactions, symbiosis and synergies. Only then can you start to understand how the system functions. I guess that you could say that to first look at the broader picture before zooming in on the detail was a most useful piece of guidance for my future work"*; and iii) *"Hardy's lectures were informative and put me in good stead for my future work as an agronomist"*.

For those thousands of students that attended Hardy's lectures and classes, the originality, both of his teaching and research, arose from his conviction of the need to consider soil, plant and environment as part of a single system (Down, 2021). In addition, Hardy played a significant role in the institutional development of both ICTA and the Agriculture Faculty of UWI as a Department Head. Recognition of the part he played in establishing the Faculty of Agriculture at UWI continues in its Frederick Hardy Building, home to the Caribbean Agricultural Research and Development Institute, by Hardy Drive which runs through the University housing area, and in the annual award of the Frederick Hardy Prize to the best final year soil science student. In addition, he was appointed Commander of the Order of the British Empire in the New Year Honours on 2 January 1950 for his work at the Imperial College of Tropical Agriculture, Trinidad. In 1968, he was elected an honorary member of the International Society of Soil Science.

CRediT authorship contribution statement

R. Wayne Borden: Writing – original draft, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Stephen H. Hallett:** Writing – review & editing, Visualization, Resources, Funding acquisition, Data curation. **Brian Kerr:** Writing – review & editing, Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Hardy Collection (Reference data) (World Soil Survey Archive and Collection - WOSSAC) - Select 'Search' -> 'Quick Search', and enter 'Hardy'

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