Plinthization - A threat to agricultural production

R. D. ASIAMAH & C. D. DEDZOE
Soil Research Institute, Council for Scientific and Industrial Research (CSIR), Kwadaso, Kumasi, Ghana

SUMMARY

The problem of land degradation resulting in insufficient food production for the ever-increasing population is recognized worldwide and some observations by scientists, administrators, and politicians on its threat to human existence, have been made and highlighted at scientific meetings, in newspapers, and other fora. The causes of land degradation are many and most of them are known and are being tackled for solutions. However, several of them have not received much attention but are grave. Plinthite and its hardened form, petroplinthite (ironpan), constitute the major forms of danger to land use. They are the results of unnoticed and gradual pedogenetic processes going on mostly in tropical soils. Scientists have worked for some time on the hardened form, petroplinthite, but the soft form, plinthite, has not received much attention. Over a third of the agricultural soils of Ghana have plinthic material and FAO reported that 96 920 km^2 of land have already hardened and made the soil unproductive. The situation may be similar for other countries in the tropics. This paper attempts to review plinthite, its physical, chemical, mineralogical and micromorphological forms, and its importance for construction and agriculture. It also warns mankind about the danger ahead if solutions are not found for the prevention of its formation and subsequent hardening to form petroplinthite.

Subject review article. Received 17 Nov 98; revised 2 Aug 99.

RÉSUMÉ

ASIAMAH, R. D. & DEDZOE, C. D.: *Plinthisation - une menace à la production agricole*. Le problème de la dégradation de terre aboutissant à l'insuffisance de la production de nourriture pour la population qui va croissante est mondialement réconnu et quelques observations sont faites par les scientifiques, les administrateurs et les hommes politiques sur sa menace à l'existence de l'humanité et mise en lumière aux réunions scientifiques, dans les journaux et aux autres forums. Les causes de la dégradation de terre sont nombreuses et beaucoup d'elles sont connues et sont en train d'être reglé. Néanmoins, il y a pas mal de causes qui n'ont pas reçu assez d'attention mais qui sont graves. Plinthite et sa forme durcie, pétroplinthite (alios ferrugineux) constituent les formes principales de danger l'usage de terrain. Ce sont les résultats de processus pédogénétique graduel et inaperçu qui passe surtout dans les sols tropicaux. Les scientifiques avaient fait des recherches sur la forme durcie, la pétroplinthite, mais la forme douce, plinthite, n'a pas reçu beaucoup d'attention. Plus d'une tierce des sols d'agricole du Ghana ont des matières plinthiques et la FAO a fait un compte rendu que 96/920 km^2 de terre est déjà durcie et le sol est rendu improductif. La situation peut être de même pour les autres pays sous les tropiques. Cet article essaie de réexaminer la plinthite, sa forme, physique, chimique minéralogique et micromorphologique ainsi que son importance pour la construction et l'agriculture. Il vise également à alerter l'homme du danger en perspective si les solutions ne sont pas trouvées pour la prévention de sa formation et son durcissement à la suite pour former la pétroplinthite.

Introduction

Degradation of agricultural lands as a result of mismanagement of the soil resources and the environment is on the increase in recent times, resulting in insufficient agricultural production which threatens food security. Several factors are responsible for land degradation. These can be off-site or *in-situ* in nature. The major off-site process is the accelerated soil erosion caused by either water or wind. Several *in-situ* processes go on almost unnoticed. These include salinization, sodification, subsoil compaction, ironpan formation, and nutrient depletion. The most damaging of all these is the ironpan formation from plinthite in the soil.

Plinthite hardens irreversibly to form ironpan or petroplinthite which has been observed and defined by several authors. It is defined, according to USDA (1975), as "an iron-rich, humus-poor mixture of clay and quartz and other diluents occurring commonly as dark red redox mottles in platy, polygonal or reticulate patterns and changes irreversibly to ironstone hardpan or to irregular aggregates on exposure to repeated wetting and drying."

Plinthite formation or plinthization, and its subsequent hardening to form ironpan or laterite by the pedogenic processes known as laterization takes place under tropical environmental conditions.

This paper is an attempt to generate awareness of the dangers of exposing plinthite through soil mismanagement - a situation that leads to its hardening and subsequent reduction of the already dwindling agricultural lands in Ghana. The authors also review the physical, chemical, mineralogical, and micromorphological forms of plinthite.

History

Plinthite was first observed and described by a British surgeon named Buchanan in 1807 when he travelled through India and observed the natives cutting the material into blocks, allowing them to harden in the sun, and then using them to build houses, bridges and pavements.

He described the material as being diffused, massive, unstratified, full of cavities and pores, with large quantities of iron, coloured red and yellow ochre, and it was soft, easily cut into required shapes which become as hard as brick, and resist air and water when dried. Consequently, he termed it "laterite", or brick stone from the Latin word "latericus", meaning brick.

Alexander & Cady (1962) described the material as highly weathered, rich in secondary oxides of iron and aluminium nearly devoid of bases and primary silicates, but may contain large amounts of quartz and kaolinite which is either hard or capable of hardening on exposure to wetting and drying. Donahue, Shickluma & Lynn (1971) also termed the material as "Plinthite" derived from "Plinthos", a Greek word for brick, and described it as a non-cemented subsurface soil material high in iron and aluminium oxides which can irreversibly be cemented into ironstone, hardpan or cemented "clumps" when exposed to repeated wetting and drying, and can be cut into bricks, dried and used for building. Several other scientists, Holland (1903), Femor (1911), Sys (1968), Daniel *et al.* (1978), FitzPatrick (1980), Russell (1989), and Varghese & Byju (1993), also studied the material and established its formation, composition, uses, and ways of hardening, after the pioneering description of the material by Buchanan (1807).

Occurrence

Plinthite occurs mostly in the tropical belt between latitudes 30°N and 30°S where conditions for its formation - plinthization - are prevalent (McNeil, 1964). But Maignien (1966) argued that plinthite is not confined to the humid tropics alone, but can also be found in the semi-arid and arid tropics.

Driessen & Dudal (1991) found plinthite in hot and humid climates with high annual rainfall and a short dry season such as in western India, West Africa, and South America, while Varghese & Byju (1993) indicated that it is widely distributed in the tropics and subtropics of Africa, Australia, India, Asia, and South America.

In Ghana, plinthite can be found in the savanna and forest zones, but it has not been described and characterized. It occurs in soils on all slopes and irrespective of parent rocks such as granitic, Birimian, and Tarkwaian rocks, but its presence in the soil is not considered as a diagnostic soil property in Ghana's Interim Soil Classification System (Brammer, 1962). According to FAO (1976), an estimated area of 96 920 km^2 of land in Ghana has already hardened from plinthite. Preliminary investigations showed that over a third of the agricultural soils in Ghana have plinthic material.

This poses a future threat to the country's food security, since the material has the potential to harden under the present rate of land degradation in the country.

Characteristics

Physical

The important characteristics of plinthite are the accumulation, form, colour, and consistence of the hydroxides and oxides of iron which impart different colouration to the ground matrix. The forms of plinthite are described as concretionary, pisolithic, slaglike, vesicular, cellular, and vermicular (Vaghese & Byju, 1993). Plinthite is pink, red, ochre and brown, often mottled and streaked (Maignien, 1966). The different colouration of plinthite is due to the oxides of iron and manganese in various degrees of hydration which occur in well-developed soils with A, B, and C horizons, and have undergone processes of eluviation and illuviation.

Chemical

The elements of interest in the formation of plinthite are Si, Al, Fe and Mn, resulting from the weathering of the common felsic to fairly mafic igneous, metamorphic, and sedimentary rocks (Eswaran, De Coninck & Varghese, 1990; Aleva, 1994). It has been observed that mature plinthite is made up principally of iron, aluminium, silica, manganese, and water. The sesquioxides and their hydrated oxides form the major constituents followed by the kaolinitic substances. They are generally poor in alkaline and alkali earth metals.

Iron occurs in plinthite in various forms but the oxides, haematite and goethite are the commonest. Other forms are lepidocrocite, maghemite, magnetite, ilmenite, and limonite (McFarlane, 1976). Aluminium occurs in plinthite as hydrates of alumina and aluminosilicates. Gibbsite, boehmite, diaspore, and amorphous diachite are forms of alumina found in plinthite. Various mineralogical forms of manganese, such as lithiophorite, birnessite, halondite, and tadorakile also occur in plinthite. Titanium is present in minute quantities in the form of ilmenite, rutile, anatase, and leucoxene (Grim, 1953).

Mineralogical

Plinthite contains a variety of minerals with highly varied mobilities. The removal of the mobile constituents and the enrichment of resistant ones contribute to the formation of different clay minerals in the material (McFarlane, 1976). Hydrargillite (gibbsite), limonite, kaolinite, halloysite, and hydrated titanic acid have been found in plinthites in West Africa (Lacroix, 1913).

The use of modern techniques shows the presence of kaolinite, halloysite, gibbsite, boehmite, haematite, goethite, maghemite, magnetite, ilmentite, zircon, anatase, and quartz in plinthite (Maignien, 1966; McFarlane, 1976).

Micromorphological

Kaolin, goethite, and haematite have been observed to be among the dominant morphological constituents (Sivarajasingham *et al.*, 1962; Daniel *et al.*, 1978). The degree of impregnation of iron is responsible for the variable optical densities. The crystalline phase of the impregnated iron is largely in the form of goethite. The spherical bodies in the matrix may be concretionary or pisolithic forms of gibbsite, boehmite, goethite or haematite (Varghese & Byju, 1993). Gibbsite and boehmite form fillings in pores and cracks in the matrix and nodules. Pores and cracks may also be lined with oriented kaolin with varying degrees of iron impregnation. Eswaran & Mohan (1973) indicated that plinthite is formed from a kaolinite mass by absolute enrichment of iron forming a vascular network.

Plinthite hardening

The removal of vegetation and soil cover causes heating of the soil and speed up oxidation and laterization which result in the formation of ironpan from soft plinthite. Various authors have indicated that plinthite will harden upon exposure to repeated wetting and drying. Gidigasu (1969) believed that plinthite hardening is due to the dehydration of hydroxides of iron, aluminium, and manganese while Alexander & Cady (1962) noted that plinthite may harden in a few years when exposed to the atmosphere. Annual bush burning and prolonged dry spells could also speed up hardening of plinthite.

Importance for construction

Interest in plinthite first arose because of its ability to irreversibly harden on exposure to form ironpan when cut into blocks and used for building purposes. Its importance in building and road construction was reported by numerous scientists including Buchanan (1807), Alexander & Cady (1962), Gidigasu (1969), FitzPatrick (1980), and Varghese & Byju (1993).

The use of the material for constructional purposes has been reported worldwide. Buchanan (1807) first noticed the natives of Kerala in India harvesting the material as brick blocks, drying, and using them for building purposes. Varghese & Byju (1993) reported that the Indians have known and used the material for over 20 centuries even before Buchanan's visit.

In West Africa, many buildings and bridges constructed with the material many years ago are still in good condition. The material is still being used for constructional purposes throughout West Africa and probably in other developing countries.

Effect on soil productivity

The material is unfavourable for agricultural production (Alexander & Cady, 1962). Its firm consistence, lack of humus and bases, and thorough leaching make the soils in which it occurs poor for crop production. The formation of ironpan in the soil, resulting from irreversible hardening of plinthite, reduces the agricultural potential of the soil as it restricts movement of air and water and downward root penetration. Donahue, Shickluma & Lynn (1971) noted that soils with plinthite, when cleared of vegetative cover, may cause the material to harden, rendering the soil difficult for use for agricultural purposes. Driessen & Dudal (1991) considered soils with plinthite as soils with low agricultural value because of frequent waterlogging, dense plinthic layers, and low fertility.

Soil erosion is accelerated in soils with plinthite because the material restricts downward movement of water, causing the materials above it to be saturated with water and then move laterally.

It has been observed in the Ashanti, Brong Ahafo, Eastern, Central, and Volta Regions that some soils that were supporting cocoa plantations have either developed firm plinthite layers or are at advanced stages and have already formed petroplinthite, resulting in the decline of the performance of the plantations. In most of these areas and also in the transition zone, the cocoa trees have died. Other plantations of citrus, oil palm, avocado pear, and coffee have also been similarly affected. It is not practicable to obtain continuous economic yields of food crops on soils with plinthite within the rooting zone.

There is a great deal of interest in finding out more about plinthization. Consequently, several UNO agencies, NGOs, and agricultural scientists throughout the tropics are working seriously to understand more about plinthic soils. The primary objective is to evolve techniques that will prevent its lateral extension and subsequent hardening, and thus facilitate its better management for economic agricultural production.

Conclusion

With the present pressure on land to produce more food, fibre, and energy for the ever-increasing population in the tropics, the soil resources must be conditioned suitably for economic production. Plinthite formation and its subsequent hardening pose a big threat to agricultural production. Deforestation, uncontrolled burning of bush, and unscientific or unconventional agricultural practices may expose plinthic material to the harsh environment, leading to the hardening of the material in our agricultural lands.

Most of the plinthite in the savanna soils have already hardened, rendering the soils unproductive. The process is extending into the transition and forest zones due to fast degradation of the vegetative cover.

If over a third of our forest agricultural lands have plinthic materials which can easily be hardened, then the country stands a big risk in losing the potential of our lands for agricultural production. Earth scientists must act now to find solutions to prevent the formation of plinthite or its hardening into ironpan (petroplinthite) so as to check this potential land degradation factor threatening our agricultural soils.

REFERENCES

Aleva, G. J. J. (1994) *Compiler: Laterites. Concepts, geology, morphology and chemistry.* Wageningen, ISRIC 169 pp.

Alexander, L. T. & Cady, J. G. (1962) Genesis and hardening of laterite in soils. *Tech. Bull.* No. 1282, CSC, USDA.

Brammer, H. (1962) Soils. In *Agriculture and land use in Ghana* (ed. J. B. Wills), pp. 88-126. London, Oxford University Press.

Buchanan, F. (1807) *A journey from Madras through the countries of Mysore, Canana and Malabar,* Chap. XII: 116. East India Co. London.

Daniel, R. B., Perkins, H. F., Hajek, B. F. & Gambe, E. E. (1978) Morphology of discontinuous phase plinthite and criteria for its field identification in the South eastern United States. *Soil Sci. Soc. Am. J.* **42**, 944-949.

Donahue, R. L., Shickluma, J. C. & Lynn, S. (1971) *An introduction to soil and plant growth,* 3rd edn. Englewood Cliff, N. J. Prentice-Hall.

Driessen, P. M. & Dudal, R. (1991) The major soils of the world. Lecture notes on their geography, formation, properties and use. Agricultural University of Wageningen and Katholieke Universiteit, Leuven. 310 pp.

Eswaran, H. & Raghu Mohan, N. G. (1973) The microfabric of petroplinthite. *Soil Sci. Soc. Am. Proc.* **37**, 79-82.

Eswaran, H., De Coninck, F. & Varghese, T. (1990) Role of plinthite and related forms in soil degradation. *Adv. Soil Sci.* **11**, 109-127.

FAO (1976) *Soil map of the world.* Vol. **VI**. Africa. Rome, FAO.

Femor, L. L. (1911) What is laterite? *Geo. Mag. NS Dec.* **8**, 454-462.

FitzPatrick, E. A. (1980) *Soils: Their formation, classification and distribution.* London, Longman. 353 pp.

Gidigasu, D. M. (1969) The formation and general characteristics of laterite and lateritic soils. *Project Report SM No. 2. BRRI,* Kumasi.

Grim, R. E. (1953) *Clay mineralogy.* New York, McGraw Hill.

Holland, T. H. (1903) On the constitution, origin and dehydration of laterite. *Geol. Mag (IV)* **12**, 529-537.

Lacroix, A. (1913) Les latérites de la Guineé et les produits d'alteration qui leur sont associés. *Nouv. Arch. Mus. Hist. Nat. Paris.* Sér **5**, 255-356.

Maignien, R. (1966) Review of research on laterites. *Nat. Resour. Res.* Ser. **IV.** UNESCO, Paris.

McFarlane, M. J. (1976) *Laterite and landscape.* London, Academic Press.

McNeil, M. (1964) Lateritic soils. *Sci. Am.* **211**, 96-102.

Russell, I. C. (1989) Sub-aerial decay of rocks and origin of red colour in certain formation. *US Geol. Bull.* No. **52.**

Sivarajasingham, S., Alexander, I. T. Cady, J. G. & Cline, M. G. (1962) Laterite. *Adv. Agr.* **14**, 1-60.

Sys, C. (1968) Suggestions for the classification of tropical soils with lateritic materials in the American classification. *Pedologie* **XVIII** (2), 189-198.

USDA (1975) *Soil taxonomy. A basic system of soil classification for making and interpreting soil surveys.* Agric. Handbk No. **436**. SCS, US Dep. Agric. US Govt. Printing Office, Washington, DC.

Varghese, T. & Byju, G. (1993) *Laterite soils: Their distribution, characteristics, classification, and management.* State Committee on Science, Technology and Environment. Thiruvanathapuram, Kerala, India. 116 pp.