Review article

The present knowledge on soil pests and pathogens in Uganda

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Abstract

To develop an inventory of the present knowledge about soil-borne pests (insects, fungi, nematodes and bacteria) in Uganda, we review in this paper, aspects of their diversity, abundance, distribution in agro-ecosystems control approaches as well as their role in sustainable land management. Knowledge gaps about the soil pests and short falls in human resource capacity are identified as possible factors affecting the development of appropriate management packages for the soil pests. Priority research areas and capacity building needs are suggested.

Key words: knowledge, pathogens, soil pests, Uganda

Introduction

The importance of soil dwelling pests, pathogens and nematodes has often been overlooked probably because of their cryptic nature and the fact that they are practically invisible to farmers. A further explanation is that, their symptoms are commonly confused with those owing to other factors such as damage by above ground pests. This may partly explain why literature on soil-dwelling pests in Uganda and elsewhere in sub-saharan Africa is scarce.

As Hillocks *et al.* (1996) correctly put it, good knowledge of soil pest problems and ability to integrate the disciplines of plant pathology, entomology, nematology and weed science within a socio-economic framework, are prerequisites for adapting the principles of integrated pest management (IPM) to the needs of subsistence farmers in Africa. The need for IPM in small holder systems is increasingly being realized in Uganda. Unfortunately, in Uganda and most likely throughout East Africa, little work has addressed soil pests and pathogens. There is for example, currently no authoritative record of losses arising out of key soil pests like termites and costs of protecting crops and buildings. It is also true that apart from the work of Emechebe (1975), there are no updated lists of diagnosed/or recorded crop disease agents in Uganda. Little is known about the roles and abundance of insect and nematode pests and pathogens as well as the interactions between/among themselves despite efforts to modernize the country's agriculture and initiatives to manage renewable natural resources better.

While the diversity, abundance and distribution of some pests and pathogens in Uganda may be implied by geographical distribution of their host plants (Hansford, 1937, 1938, 1943; Emechebe, 1975) many issues related to diversity, succession and factors determining their spatial patterns are not yet studied. This signifies the presence of probably a huge knowledge gap, requiring more research before sustainable integrated management approaches can be formulated for the soil pest complex.

Soil pests in agricultural systems

For purposes of this review, the term 'soil pests' is used to include the complex of soil inhabiting insects, soil borne plant pathogens and root-invading nematodes, which

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affect crop plants. Soil borne diseases are defined as those caused by pathogens which invade the root or lower stem of their host and are capable of survival in the soil, in the absence of the main host, either as saprophytes or by the production of resting spores. We will deliberately restrict ourselves to those pathogens either recorded or diagnosed in Uganda.

Diversity, abundance and distribution of pests and pathogens

Lists of soil- borne crop pathogens and insect/nematode pests are presented in Table 1. Where possible and for purposes of this record, the table indicates agent host plant and author. The majority of these pathogens are fungi.

Most of the soil pests are not specialized and therefore have a wide host range. For example *Rhizoctonia bataticola*, *Fusarium* spp. and *Verticuluim dahliae* infect a range of plant genera (Table 1). Some species of *Fusarium*, however, exhibit a considerable degree of host specialization and are more effective pathogens, being less dependent than non-specialized pathogens, on host predisposition for successful infection. In crop systems, the bacterial wilt pathogen, for example, has a wide host range but is particularly damaging to members of the solanaceae. Root knot nematodes (*Meloidogyne* spp.) also have a very wide host range but are more damaging to the solaneous and leguminous crops, particularly tomatoes.

Major pest species of termites belong to the genera *Pseudocanthotermes Marotermes*, *Odontotermes* and *Microtermes*. Damage varies from superficial to death of the plant. Most damage, however, appears restricted to exotic plants, which are often stressed when grown in tropical environments. Most termite species in agricultural fields do not damage native crops.

There is no reliable information either in Uganda or elsewhere in sub-saharan Africa to enable a comparison of soil pests, especially pathogens, in agricultural systems to natural systems. There are examples in Uganda of increased infection of some pathogens to crops grown on soil converted from a forest to agricultural land. For example, the *Armillaria collar* rot (*Armillaria mellea*) as well as the *Fomes* root rot (*Fomes lignosus*), which are usually of minor importance as diseases of rubber become very severe when the crop is planted on forest land.

A comparison of ecosystems in relation to diversity and abundance of soil pests especially pathogens is practically difficult, particularly for Uganda, because of lack of reported studies in ecosystems other than the agricultural ecosystems. It is probable that the forest ecosystems have the greatest diversity and abundance of soil borne pests because of their relatively stable ecological state. Ecosystems such as the semi-arid vegetative, savanna mountains are regularly disturbed by factors such as over grazing and bush fires (Pomeroy & Rwakaikara, 1975) and agricultural practices (Okwakol, 1994), which may have direct impact on many soil pests.

Diversity, abundance and distribution of pests and pathogens

It is possible that, in addition to the soil pests indicated in Table 1, many other species have not yet been identified. The present record of pests of different categories clearly shows the species richness in the agro-ecosystems. This helps to emphasize the need for an integrated approach, while designing pest management programmes.

There is a body of information on the biology and distribution of soil pests in Africa as well as the taxonomy of some genera. For Uganda, this is especially so for termites and pathogens (some fungi and bacteria) but many other soil borne pests are poorly understood (Hillocks *et al.*, 1996). The most important factor influencing the spatial distribution patterns of soil pests is probably the distribution of host crops. Detailed distribution maps for soil insect pests can be found in IAPSC (1995).

Temporal patterns (succession)

Some soil pests are widespread in Africa while others have a more limited distribution and, within areas where they occur, the severity of damage they cause may vary considerably (Hillocks *et al.*, 1996). In many places, their distribution is affected by a number of factors, especially soil type, soil moisture, temperature and vegetation cover.

Soil moisture

Soil moisture, and therefore indirectly rainfall, is an important determinant of the distribution of soil pests both geographically and within the soil profile. There are, for example, generic or species related preferences for different levels of moisture between different termites. In Kenya, for example, micro termites predominate in well drained soils but in areas of high ground water levels, *Odontotermes* spp. and *Psendacanthotermes spiniger* are among the most

Table 1 Soil-borne crop pathogens, insect and nematode pests recorded in Uganda

Agent	Host plant	Reference
Fungus		
Marasonius spp	Bananas	
M. sacchari	Sugar cane	Hanford 1940
Rhizoctonia bataticola	Sweet potato, cotton, citrus	
	Ground nuts, roses, sorghum	
Pythium spp.	Tobacco	
P. debaryanum Hesse	Tobacco	
Verticullium dahliae	Cassava, cotton, egg plant, okra	
	Simsim	
Piricularia oryzae	Rice	
Fusarium graminiaerum	Maize, sorghum	
Fusarium spp.	G.nuts, sugar cane, cotton	Hansford & Hays 1940
Fusarium oxysporum	Bananas	
Rhizoctonia bataticola	Bananas, simsim, beans, okra,	
Capsicum spp.		
Sclerotinia ricini	Castor	
Sclerotium rolfsii	Soybeans, Ground nuts, lucerne, capsicum, solanum potato	
Sclerotium capirorum	Onions	
Pellicularia rolfsii (sacc). West	Beans	
Alternaria solani	Tomatoes	
Alternaria spp.	Simsim	
Rhizoctonia bataticola	Simsim, coffee, field peas	
Fusarium oxysporium	Simsim, g.nuts, okra, pigion pea, tomato	
Macrophomia phaseoli	Beans, lucerne	
Fusarium moniliforme	Maize, soyabeans	Hansford 1940
Fasarium solani	Cotton, onions, cow pea, Solanum potato	
Verticillium dahliae	Passion fruit, cotton, cocoa, tomato	
Cercospora spp.	Cotton	
Rhizoctonia solani	Cotton, coffee, tomato	
Polyporus coffeae	Coffee	
Armillaria mellea	Coffee, cocoa, forest trees, roses, rubber	
Rhizoctonia lamellifera	Rubber and tea	Emechebe, 1975
Daetuliphora tarii	Beans, cowpeas	
Phytophora spp.	Citrus, sweet potato	
Fomes noxius (Corner)	Coffee	
Capnodium brasiliense	Coffee	
Rhizopus nigricans	G.nuts	
Sphacelotheca reliana (Kuhn)	Maize	
Gibberella fujikuroi	Finger millet, maize	
Gibberella zeae (Petch)	Maize	
Tolyposporium penicillariae	Bulrush millet	
Tolyposporium enhrenbergis (Kuhn)	Bulrush millet	
Peronospora destructor (Berk)	Onions	
Nectria haematococca (Berk)	Passion fruit	
Actinomyces scabies (Thax)	Solanum potato	
Helicobasidium bagisporum (Wakef)	Roses	
Fomes lignosus (Klotzsch)	Rubber	
Sphacelotheca sorghi	Sorghum	

Table 1 Continued

Agent	Host plant	Reference
Sphacelotheca cruenta (Kuhn)	Sorghum	
Colletotrichum glycerine	Soyabeans	(Lehman & Wolf)
Thielayiopsis paradoxa (De seynes)	Sugar cane	Van Hohnel, 1937
Phytophora parasitica Var. nicotianae	Tobacco	Tucker, 1927
Septonia lycopersici (Speg)	Tomato	
Bacteria		
Pseudomonas solanacearum	Tomato, G.nuts, tobacco	Smith, 1956
Pseudomonas solanacearum	Solanum potato	Smith, 1930, 1964
P. marginalis (Brown) Stapp	Solanum potato	
Agrobacterium tumefaciens	Roses	Smith &Toms, 1942
Corynebacterium michiganense	Tomato, wheat	Smith & Jensen, 1974
Mealy bugs		
Pseudococcus latipes	Coffee (symbiotically with	
Planococcus kenyae	Polyporus coffee fungus	
Nematodes		
Radopholus similis	Banana	Haig, 1970
Pratylenchus goodeyi	Bananas	
Helicotylenchus multicinctus	Bananas	
Heterodera mariani	Tobacco	
Melodogyne spp.	Egg plant, passion fruit, pigion peas	
	Simsim	
Helicotylenchus spp.	Simsim	
Meladogyne favanice	Tobacco	
Insects		
Cosmopolits sordiclus	Bananas, indigeous	Hargreaves, 1960
Cylas formicarius	Sweet potatoes, indigeous	
C. puncticolis	Sweet potatoes	
Peleropus batatae (curculionidae)	Sweet potatoes Marshall	
Gryllotalpus africana	Rice	Hargreaves, 1940
Syagrus calcaratus (Fab.)	Cotton	Taylor, 1940
Brachytrypes membranaceaus	Cotton, tobacco	Gwynn, 1940
Syagrus	Cotton	
Psuedococcus citri (Coccidae)	Coffee Hargreaves	
	G.nuts	Hansford & Hages, 1940
	Alemu, 1996	
Pseudacanthotermes militaris (Hagen)	Maize, Soy	
P. piceus (Sjostedt)	Maize	
Psendacanthotermes spiniger (Sjostedt)	Maize	
Pseudacanthotermes	*bellicosus* (Smeathman) Maize	
M. falciger (Gerstacker)	Maize	
M. subhyalinus (Rambur)	Maize	
Odontoterms badius (Haviland)	Maize	
O. culturarum (Sjostedt)	Maize	
O. fulleri (Emerson)	Maize	
O. kibarensis (Haviland)	Maize	
O. latericius (Haviland)	Maize	
O. monodon (Gerstacker)	Maize	
O. nolaensis (Sjostedt)	Maize	
O. patruus (Sjostedt)	Maize	
Microterms kasaiensis (Sjostedt)	Maize, soy, sorghum	Sekamatte, 1998

common (Kooyman & Onck, 1987). Soil moisture and rainfall levels also affect other insects. Dry conditions for example, are reported to favour *Gonocephalum simplex* (Milambo, 1983).

In case of pathogens and nematodes, adequate soil moisture and high temperatures allow for many generations of microorganisms to be produced relatively quickly and the disease potential is therefore greater than in lower temperature environments. Thus the distribution of many soil borne pathogens is strongly influenced by the predominating moisture status of the soil.

Temperature patterns

The distribution of soil pests can also be affected by general temperature patterns which are influenced by altitude (Villan & Wright, 1990). For instance, in Kenya, *P. spiniger* is not found above 1700 m while *Microtermes* is absent above 1900 m (Kooyman & Onck, 1987).

Crops grown in arid regions suffer fewer diseases than those in humid areas. Many pathogens are, however, adapted to causing disease under hot, dry conditions (Hillocks *et al.*, 1996). For example, the fungus *Macrophomina phasiolina* causes root and stem rots in a very wide range of hosts under arid conditions. Crops grown in wet, warm environments are susceptible to seedling disease and crown rot caused by *Sclerotium rolfsii* where conditions are cool and wet, root disease and damping off caused by *Pythium* and *Phytophora* may be found. Plant parasitic nematodes are found almost everywhere crops are grown. Survival and invasion by plant parasitic nematodes, however, are favoured by moist soils. Nematodes are not adapted to very wet conditions and, allowing for some variation between genera, greater populations are to be found in well drained sandy loam soils than in clay soils which are poorly drained.

Cultivation regimes

The density of soil pest populations and intensity of pest attack on crops is often related to prior cultivation practices. For instance, wire worms and white grabs are often present in greater numbers in land, which has been left fallow or which has been sown to pasture or cereal crop (Belcher, 1989). Clearing of woodland removes food and nesting sites, while mechanical cultivation destroys mounds and termite nests in the upper soil layers altering termite numbers and species composition. Several studies have reported a decline in certain termite species with the introduction of agriculture as nest sites are destroyed and preferred food sources removed (Wood, Johnson & Ohiagu, 1977; Okwakol, 1994). Continuous cultivation, which is normally practiced out of necessity owing to land shortages in many parts of Uganda and elsewhere in Africa, leads to a build up of soil borne pathogens and nematodes especially, where traditional mixed cropping systems have been abandoned in favour of monoculture (Hillocks *et al.*, 1996). In Uganda, this has been documented as especially serious with bacterial wilt of tomatoes (*Pseudomonas solanaceurum*) and also with the root-knot nematode (*Meladogyne* spp.) attacking egg-plants.

The build-up in inoculum of soil-borne fungal pathogens can further be exacerbated by planting infected seed. As a traditional practice, subsistence farmers in Uganda retain their own seed for planting over seasons. This continues the cycle of infection for commonly seed borne pathogens such as *Fusarium* spp. In general, nematodes and soil borne pathogens tend to build up under cultivation, especially if land is continually planted one or a few crops (Hillocks *et al.*, 1996). Some diseases can occur on land in the first year of cultivation after bush clearing, indicating the presence of the causal organisms of the indigenous flora. For instance, vascular wilt caused by the *Verticilium dahliae* (Evans, 1968), root rot caused by the fungi, *Armilleria mellea*, can be a problem on cassava when it is planted immediately after forest clearance but quickly declines in successive crops.

Inter or mixed cropping

Another land use practice that possibly affects the temporal patterns of soil pests is inter-cropping or mixed cropping. The practice has been shown to reduce above ground insect pest numbers and damage in a wide variety of situations but very few studies have focussed on inter-cropping with respect to soil pests. Examples in inter-cropping sweet potato with maize or soybean or maize, in Guinea reduced weevil damage to tubers but also decreased the overall yield and value of the crop (Yaker, Hill & Chiasson, 1992). In Uganda, inter-cropping maize with soybeans reduces maize attack by *Pseudacanthotermes* but not *Macrotermes*. The maize/sorghum inter-crop, on the other hand, reduces damage to maize by both genera (M. B. Sekamatte and A. Russel-Smith, unpublished data). Gold & Wightman (1991) found no effect of inter-cropping groundnuts with sunhemp on termite abundance or damage to groundnuts in India.

Soil fertility

While soil of low fertility is not necessarily more attractive to soil borne pathogens, crops which are stressed due to nutrient deficiency are often prone to disease (Hillocks *et al.*, 1996). Many soil borne fungi are capable of only invading only slowly growing plants or plants already under stress (e.g. seedling infection by *Rhizoctonia solani*), or they may invade a vigorous plant but the infection remains latent until the plant becomes stressed, as with *M. phaseolina*. Survival of soil pests is directly linked to soil fertility. Pomeroy & Rwakaikara (1975) noted positive correlations between soil organic matter and populations of termites. In related studies, Okwakol (1989), found a positive relationship between termite survival rates and soil organic matter content.

Crop residue management

The methods of crop residue disposal may have an impact on the prevalence of both insect pests and pathogens in the soil. Continuous removal of crop residues from a field leads to rapid decline in fertility and deterioration of soil structure. Low levels of organic matter in the soil lead to a decline in populations of both macrofauna (Okwakol, 1989; Okwakol 1991) and microorganisms, which compete with pathogenic fungi and nematodes and possibly also adversely affect the activity of Mycorrhiza fungi (Hillocks *et al.*, 1996). The resulting loss in vigour renders crop and plants susceptible to soil borne fungi and nematodes. The loss of soil structure results in poor holding capacity and increased soil temperatures, both of which predispose crops to charcoal rot caused by *Macrophomina phaseolina* (Odvody & Dunkle, 1979). Maintaining maize stovers in the fields has shown variable responses to levels of termite infestation of maize. While in some cases the stover may increase termite populations in the field, a recent work in Uganda indicates that certain quantities of mulch may significantly reduce termite attack on growing maize (Sekamatte, Ogenga-Latigo & Russell-Smith, 1998a,b). It is possible that the mulch, apart from serving as alternative food source especially to subterranean termite species, may also provide an ideal nesting site for predatory (especially Myrmicinae and Componotine) ants (Sekamatte *et al.*, 1998a,b).

Burying stover together with fish bone – based bait significantly reduced *Pseudacanthotermes* attack on maize (Sekamatte *et al.*, 1998a,b). Burying crop residues by making ridges in furrows of the previous season's crop, may tend to increase disease. This might occur if ridging is carried out late, or under dry conditions, un-decomposed crop residues can increase the incidence of seedling disease caused by *R. solani, Sdepotium rolfii* and *M. phaseolina* (Hillocks *et al.*, 1996).

Water management

Water lodging retards plant growth and predisposes the crop to infection by soil fungi, which are favoured by wet conditions. *Pythium* and *Phytophora* for instance, are favoured by cooler temperatures. Infections by *S. rolfii* are greatest under warm, humid conditions but the fungus is sensitive to oxygen depletion and does not thrive in water logged soil. In Uganda, *Pseudomonas solanacearum* attacking groundnuts and *Solanum* potatoes, is associated with water logged soils (Emechebe, 1975).

Importance of soil borne pests and pathogens in the ecosystem

At the landscape level, soil pests, notably termites, constitute an important component of soil because of their role as decomposers. Termites are known to be responsible for the decomposition of up to one-third of annual grass, wood and leaf litter in their habitats (Collins, 1979). They contribute to the homogenization and regeneration of the entire soil body (Hesse, 1955; Nye, 1955; Watson, 1962). Experiments conducted to determine soil fertility of termite mounds in Africa, however, have sometimes given rise to divergent views as to the importance of termites in soil fertility. Moduakor, Okere & Onyeanuforo (1995) for example, established that nutrient levels were greater in *Cubitermes* mounds than in surrounding soils but less in *Macrotermes* mounds, with Ca : Mg ratio being lower for both. On the contrary, the K : Mg ratios were generally lower in crops grown on the termite modified soils of both species, than in the surrounding soils. Termites, especially the alates, are an important food source in many parts of Uganda. Except for their known pest status, the importance of many pathogens and other soil dwelling life forms remains largely unknown.

Indigenous knowledge about soil pests and pathogens

An on-going study recently evaluated farmers' perceptions of termite damage and available control practices in maize. It was found that in most parts of Uganda, farmers have good knowledge of termite species that are pests to crops and those that damage buildings. Of the interviewed farmers (70–100%) across five districts ably named the various termite categories in local languages (Achola, Sekamatte & Russell-Smith, 1999). In some cases, however, the farmers indicated that it was the subterranean termite species, which were pests of crops. This was probably because the subterranean termite species are more easily seen in foraging parties. In general, there is almost total lack of indigenous knowledge about nematodes (Namaganda, Personal Communication) and soil pathogens (Kangire, Personal Communication) affecting crops, among farmers in Uganda.

Country capacity for pests and pathogen studies

Analysis of research projects within the National Agricultural Research Organization (NARO) and Makerere University Faculty of Agriculture indicates that there are relatively few studies directed at solving soil pest problems compared with above ground crop pests (Naro Projects Manual, 1998).

In terms of availability of human capacity, there is a huge deficiency in both the research institutes and university system. Within NARO, for example, there are currently only five entomologists and less than ten plant pathologists distributed within the various commodity programmes over four crop and one forest research institute (Naro Staff Book, 1999). Within the NARO system, there is currently one nematologist at Kawanda and one soil microbiologist based at Serere. At the Makerere University Faculty of Agriculture, there are two entomologists and two plant pathologists. None of them is currently involved in soil pest pathogen management research. Analysis of on-going research shows that it is probably the banana and to some extent horticulture research programmes focusing on nematodes and the cereals programme focusing on termites in maize. This leaves a lot to be desired in terms of national capacity for research in soil pests and pathogens.

A major constraint in soil pest research in Uganda is probably the absence of taxonomic services, and as such, apart from small collections of banana nematodes at Kawanda, collections of some common termites at the Makerere University Zoology Department and recently at Namulonge Agricultural Research Institute (NAARI), no reference collections exist for identification services. There is also no impetus for young scientists and students at university to specialize in biosystematics. This, in addition to prohibitive costs of taxonomic services outside the country, makes research in this area less attractive.

Pests and pathogens and sustainable land management

A review of the past studies on the impact of crop diseases and pests on Uganda agriculture (e.g. Emechebe, 1974, Emechebe & Mukiibi, 1974; cited by Emechebe, 1975; Robinson, 1940; Kangire, 1998; Rukazambuga, 1996) indicates that few reliable estimates of crop losses due to soil borne pests exist in Uganda. For example, of 13 crop loss studies listed by Emechebe (1975), none dealt with soil borne pathogens. The only figures available are those of Rukazambuga (1996) indicating up to 50% yield loss in bananas due to weevils at 4th ratoon and Kangire (1998) reporting, 100% yield loss in bananas due to *Fusarium* wilt.

In all studies undertaken to address soil pest problems in Uganda, the approach has been to tackle individual pests, diseases and weed problems. All organisms form part of an interactive complex and should be studied as such, if sustainable management strategies are to be developed. Elsewhere, Hillocks *et al.* (1996), associations between nematodes and soil borne diseases, is well documented particularly with respect to *Fusarium* wilt and root knot nematodes, on a wide range of crops. Where the fungal pathogen and nematode occur together, the incidence of *Fusarium* wilt is higher than in the absence of the nematodes (Hillocks & Bridge, 1992). Less is known about the effect of nematodes such as *Melodogyne javanica*, on infection by nonspecialized pathogens.

Damage caused by soil-inhabiting insects such as termites also enhances infection by soil borne fungi. Charcoal rot of maize, caused by *M. phaseolina* often occurs too late in crop development, to cause yield loss but the consequent lodging allows termites to destroy the crop as it lies on the ground. Termites have been shown to carry, on their bodies, spores of various pathogens such as *Fusarium* spp. (Johnson & Gumel, 1981). Similarly, Upadhyay & Rai (1982) showed that termite carrying spores of *Fusarium* spp could infect pigeon peas with *Fusarium* wilt. No such studies have been carried out in Uganda, but their results could yield essential information for the management of pests and diseases in agro-ecosystems.

Damage to roots by plant pathogens may predispose the plant to attack by soil pests. Mercer (1978) considered that groundnuts, in Malawi, were more susceptible to termite attack if they were infected by fungi such as *Fusarium solani*.

Research on termites in annual crop systems in Uganda, is still in its infancy and based on design of on-going projects. Few aspects are likely to be addressed. Given the increasing importance of these pests, the above mentioned interactions among soil inhabiting pests and the need for integrated packages, a lot of gaps are already evident. The practice of inter/mixed cropping is still dominating small-holder agriculture in Uganda.

While some studies have been undertaken to evaluate the practice of inter-cropping in respect to aphid infestation (Sekamatte, 1994), the interactions between various above ground organisms within these crop complexes remain anecdotal.

Management of soil pests and pathogens

There are several restrictions on small holder farmers in Uganda to adopt modern crop protection. These include, for example, shortage of land, labour and cash (Hillocks *et al.*, 1996). These restrictions on small holder capabilities mean that technical solutions to pest problems cannot be produced solely on the research station premises. Farmers' own needs and capabilities must be considered.

A major knowledge gap in the case of Uganda is that no clear understanding of traditional pest control techniques exists. This is clearly shown by the absence of mention of any such techniques in all available literature (Emechebe, 1975) and all crop production brochures prepared by research and extension staff. This has probably been as a result of the low involvement of social/rural economists in technology development in the past.

Traditional soil pest/pathogen management practices include the use of agents such as wood ash against soil pests termites and banana weevils. Various plant extracts (e.g., neem) are also used against termites in many parts of Uganda. The extracts are used against a range of symptoms due to various pathogens. Detailed surveys need to establish a complete list of plants traditionally used as pesticides. Through long-term selection/maintenance of their own seed, farmers have always selected varieties resistant to major pests and diseases. This has probably accounted for the low adoption rates of new high yielding varieties from research stations e.g. the new millet and sorghum varieties at Serere (Anon, 1999). Other traditional methods include directing storm water into *Macrotermes* mounds, application of tobacco in/on soil, pouring fish soup, or putting dead snakes into mounds as well as rotation of crops where land size permits (Achola *et al.*, 1999). It is, however, not documented how much farmers in Uganda know about particular crop symptoms of pest/disease infestation/infection and some of the agronomic practices, which influence crop responses.

Elsewhere, for example, in Malawi, farmers were able to distinguish precisely which maize plants in a field were affected by pre-emergent striga and which parts of the plant (Hillocks *et al.*, 1996). They were well aware of the link between low fertility and striga damage to maize. Such information needs to be documented for Uganda before extensive control methods are evaluated.

Hillocks *et al.* (1996) discussed in detail the modern approaches to soil pests and pathogen management in sub-saharan Africa. These include host plant resistance or crop tolerance, modification of cultural control, multiple cropping, biological control, chemical control (including fungicides, nematicides and insecticides) and use of pheromones to control soil-dwelling insects. They elaborated the role of IPM in small holder agriculture noting that the challenge is to provide recommendations for control of a range of pests, pathogens and weeds within one system. Apart from nondeliberate use of multiple cropping e.g. maize/legumes (maize/cow peas) which decrease soil populations of root-knot nematodes, it is probably chemical control using a range of fungicides for seed dressing and long persistent termiticides (e.g. lindane, Marshal suscon) that has dominated soil pest control in Uganda's agriculture (Alemu, 1996). It is not known what impact the banning of organochlorines has had on soil-borne pest/pathogens and what factors are contributing to the regulation of the pest complex in the absence of these chemicals. This applies to other ecosystems e.g. rangelands and forest systems where organochlorines were applied against ticks, tsetse and other pests.

Policy relationships

Recent advances in termite research have singled out biological control as a possible solution to these soil pests (Grace, 1997). While this may equally be true for a range of other soil pests, there are still several policy issues to be addressed before full scale research in biological control can be undertaken. For instance, there are no regulatory guidelines for importation, testing or application of biological control agents in Uganda (Mugoya, Uganda National Council of Science and Technology – Personal Communication). The many existing policy gaps directly hinder progress on this type of research. A policy framework needs to be worked out to harmonize issues involving stakeholders notably, the Uganda National Council for Science and Technology, the National Environment Management Authority, the National Agricultural Research System (NARS) and the political authority.

Future priorities for research application and capacity building

In the past decade, the need to embrace the philosophy of IPM in Uganda became eminent. Till now, however, most if not all, crop protection programmes continue to focus on single pests in single crops; a situation that rarely exists in the majority of farming communities in Uganda. Mixed cropping and mixed pest infestations are what exist. Future research therefore, needs to be re-oriented to focus on integrating the various component technologies within the farmers, socio-economic framework. In the light of the pest complex and the unknown interactions with a range of soil pests, the various technologies should be integrated into packages for a particular cropping situation.

On the basis of comparatively low on-going research on soil pests as reflected by NARO's current projects, it can be concluded that little focus is placed on soil pests. This is largely because of insufficient human resource within the research system. In this review, therefore, we found it appropriate before proposing future research imperatives to identify the needs for capacity building.

Capacity building needs

For sustainable management of soil pests and pathogens, a capacity building initiative is required to re-orient practising crop protection scientist to begin addressing soil pest problems in a holistic manner, as opposed to the single problem approach. To achieve this, in the medium–long term, the training of pest management scientists (entomologists and pathologists) at university should include, as part of the curriculum, concepts and practices of agro-ecology probably as a stand-alone course unit. This should produce scientists who view every pest problem as an integral part of a large and dynamic system.

- Existing and upcoming crop protection projects ought to offer agro-ecology training for practicing crop protection scientists within the NARS and universities. This is considered an essential step if the entire research system is to make a change that suits the requirements of the IPM philosophy.
- A critical mass of young scientists be trained as specialist taxonomists of soil pests. They should then constitute staff of the pest identification centre which could be appropriately located within the NARS centers. This capacity building should coincide with the development of appropriate infrastructure notably laboratories.

Future research imperatives

1 Nation-wide survey to enable a clear understanding of the abundance, species diversity, factors affecting distribution, factors predisposing host crops to specific soil pests. The only available source of information showing what plant pathogens occur in Uganda is probably that of Emechebe (1975) and termite species by Wanyonyi (1984), both of which are overdue for revision.

2 Research on the indigenous knowledge and soil pest control systems. These should be given high priority because even in the absence of high technology in-puts e.g. pesticides and fertilizers, farmers managed to produce crops. It is also possible that they were developed from sound understanding of the agro-ecosystem.

3 Analyses of interaction of soil pests (pathogens, nematodes, insects and weeds) within themselves and between them and critical factors in the environment such as soil fertility, moisture, local natural enemies etc. Most reported soil pest control studies have focused on chemical control, using nematicides and long persistence organochlorines against termites (Alemu, 1996) but none recorded has considered assessments of treatment impact on the natural enemies of pests. This is, however, a critical issue in view of the increasing concern on soil health and environment in general.

4 Investigating the causes of dramatic increase in incidence of soil borne pests and diseases in recent years. What linkages? Recently, termites have been named as a factor in the desertification problem in the cattle corridor especially the Nakasongola area (Anon, 1999). Difficulties, however, have arisen in explaining the principal factors contributing to the upsurge of termites as drought, bush fires and grazing have always been common factors. Now that people in the cattle corridor have embarked on crop agriculture, serious soil pest problems are envisaged. Consequently, long-term ecological studies are required to guarantee sustainability of mixed farming in this ecosystem.

5 Impact studies of the new generation pesticides, commonly branded as 'safe pesticides' on soil pests and associated natural enemies within Uganda's agro-ecosystems. In a recent survey of eastern Uganda, elders linked the raising termite problem and low abundance of predatory ant species to aerial sprays of dieldrin against tsetse flies which went on up to around the late 1970s. This needs investigation.

6 Together with socio scientists, crop protection scientists ought to formulate appropriate methods of integrating existing component technologies such as resistant cultivars, effective crop mixtures such as maize/cow pea against nematodes, as well as suitable rotations to be transferred to farmers through appropriate extension methods such as Farmer Field School Models.

7 Crop loss studies to enable a logical ranking of the various pests in importance. Crop loss studies have not been conducted or updated for almost the whole pest complex in Uganda.

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