Pest dynamics, ecology and climate change: underpinning policy interventions for improved pest management among CARICOM member states

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SUMMARY

1. The issue of climate change and its impacts is one of the most challenging global issues today with the most visible effects being manifest in the many extreme weather events that are now experienced so regularly in nearly all geographic regions of the world and which are responsible either directly or indirectly in several tragedies in so many countries. Less newsworthy, perhaps, but of extreme concern to its many stakeholders are the impacts of changing climatic factors on agriculture. Also of concern to the global agriculture community is the problem of invasive pest species or new pest introductions and their establishment in areas where they had not been historically present. While this phenomenon of pest movement is not a new occurrence, however, with the increased movement of peoples and trade between countries, this has provided an artificial pathway mechanism for the movement of pests, either inadvertently or deliberately. Additionally, pests could also move naturally into new regions. However, what is very worrisome today is the facilitation and exacerbation of this problem of the distribution of new and invasive pest introductions as a result of changing climatic conditions. Such climate variability may enhance the establishment of pests into areas which had been previously unfavourable for survival and establishment because of unsuitable climatic conditions.

2. Within the wider Caribbean geographic area there have been several introductions of invasive pest species over the past two decades, many resulting in enormous economic loss to regional agriculture. Examples such as Coconut Lethal Yellowing disease, Black Sigatoka disease of banana and plantain, the infamous Pink Hibiscus Mealybug and Citrus Tristeza virus all readily come to mind. The management of these and other introduced pest species have all proved to be quite challenging to both national and regional crop protection personnel.

3. One of the constraints to better management of these pests has been insufficient knowledge and understanding of pest-crop dynamics and the roles, for example, that beneficial organisms, climate changes and even agricultural policies may have on the actual pest populations and on the selection of appropriate pest management solutions.

4. The role of changing climatic conditions on pest distribution and establishment is difficult to correlate. The more long term effect on climate change on future pest distribution is even more difficult to predict and several reports have emphasised the complex interactions between changes in climate, crops and pests. However, there is much scientific evidence to support the view that climate change will result in a higher probability for the entry, establishment and spread of crop pests.

5. Implementation of certain government policies may also impact on the introduction and establishment of new pests in a country. Such policy decisions as establishing new trade links for

agricultural commodities, increased movement of peoples through the encouragement of tourism, changes in pesticide usage or promotion of agricultural diversification could all lead to new pest risks.

6. Governments need to define new policy measures or implement those relevant policies that have already been identified to deal with the critical problems on introduced crop pests and the impacts of changing climatic factors on invasive pest species.

7. Both national action and regional collaboration are critical in the mitigation of the impacts of the growing number of actual introductions and potential threats of new invasive pest species into the CARICOM or even wider Caribbean region. This is even more vital, especially given the fact that any new pest introduction in one country will invariably and rapidly spread throughout the region. However, CARICOM countries face many constraints to effectively deal with the prevention, early warning, early control eradication of invasive pest introductions.

8. Some identified policy interventions include:

8.1 ***The updating and/or strengthening of plant protection and quarantine (PPQ) legislation and regulations***. PPQ legislation in most countries is outdated and cannot meet the modern phytosanitary requirements demanded by current international agreements. One country's plant protection act dates to 1923 and it is incomprehensible how any country can expect to meet modern phytosanitary obligations with near century-old legislation. Governments of those countries with outdated PPQ legislation and inadequate regulations are, therefore, strongly urged to make an urgent effort to enact modern legislation not only to enable the required action to safeguard their borders from foreign pests but also to comply with the international obligations of the International Plant Protection Convention (IPPC) and World Trade Organisation (WTO) agreements to which they are signatory. The expected impacts of climate change and changing weather patterns on pest introductions may even necessitate the drafting of new legislation or amendment of existing legislation where applicable.

8.2 ***Increased support for research***. Many regional governments have never had or have had only limited capability to develop an effective national agricultural research capacity mainly due to the insufficiency of both human and financial resources. The formation of CARDI probably served to exacerbate this situation as some countries, given CARDI's mandate to provide the research and development needs of the region, may have relinquished this responsibility either wholly or partially to CARDI. However, despite the important role that CARDI has played and continues to play, countries have the obligation to still develop, to the extent that they are able to, their own research capability.

8.2.1 There also needs to be greater recognition of the role and contribution of the regional universities and other regional research institutions while, at the same time, for these bodies to be critically supportive of any official governmental policy and action in identifying and mitigating, for example, the threats of new pest species or of the impacts of climate change on regional agriculture. Also, these institutions have to take a major, if not leading, role where countries lack the national capability and capacity for research.

8.3 ***Strengthening phytosanitary capabilities***. The IPPC and the WTO SPS Agreements have established a framework of rules and guidelines to assist countries in the implementation of effective phytosanitary measures to prevent the introduction, establishment and spread of pests. However, there is considerable difference in the capacity of CARICOM states to apply the measures outlined in these two agreements. Governments are urged to comply with these obligations under these two international agreements to the extent that they are able to do.

8.4 ***Strengthening pest risk analysis capacity***. Modern phytosanitary decision making must be science-driven or be technically-justified according to the IPPC and WTO SPS agreements and such science or technical justification is derived from the conduct of a pest risk analysis (PRA). However, despite the development of several international guidelines and standards for the conduct of PRAs, most CARICOM member countries have not been making adequate use of PRAs in their phytosanitary decision making or in using the results of PRAs to assist in the setting of phytosanitary regulations. It is essential that all countries establish PRA units. Alternatively, especially for the benefit of those countries unable to establish national PRA units, governments should agree to establish a regional PRA facility. Such a unit could be incorporated as a division of CARDI or at CAHFSA, when this latter becomes a reality.

8.5 ***Improving diagnostic capability***. One recurring constraint to the better delivery of pest management capability in the CARICOM region is the timely identification of newly introduced pest species principally due to the lack of trained taxonomists in the region. It may be therefore now necessary to implement new approaches to pest diagnosis as is being done in other countries. With the wide availability of the internet, the development of distant diagnostic tools and diagnostic networks is now possible. The Caribbean Invasive Species Surveillance and Information Programme (CISSIP) which was a part of the Caribbean Invasive Species Intervention Strategy (CRISIS) of which CARDI had a lead role, together with the USDA APHIS and the University of Florida had initiated a project to implement a Caribbean Regional Diagnostic Network with technical support provided by the University of Florida. The outcome of this initiative is unclear but this is just the kind of effort that requires the support of regional governments to be sustainable. It is recommended that CARICOM Governments actively pursue and support this or other similar initiatives.

8.6. ***Rationalisation of Phytosanitary Services***. Fragmentation of phytosanitary services within and between ministries may often lead to an inefficient delivery of such services. Many countries have now enunciated a policy for the establishment of an umbrella National Agricultural Health and Food Safety Agency (NAHFSA), bringing together all the different agencies of plant (and animal) health including plant and animal quarantine so as to maximise their efficiencies and facilitate better administration and delivery of these services. Belize was the first CARICOM member country to do so with the establishment of the Belize Agricultural Health Agency (BAHA) in 2000. Recognising a similar need for a complementary regional agency with a parallel mandate, CARICOM Governments took a policy decision to establish the Caribbean Agricultural Health and Food Safety Agency (CAHFSA). The Caribbean is the only region without a functioning regional plant protection organisation as mandated by the IPPC and this would be one of the roles of CAHFSA. Governments are therefore strongly urged to implement their policies to establish their NAHFSAs as well as to do all that they can to ensure that CAHFSA becomes operational in as speedy a time as possible.

8.7 ***Improved public education and dialogue on climate change and pests***. In the 2009 Liliendaal Declaration on Climate Change and Development, CARICOM Heads of State resolved “to institute a comprehensive programme of public awareness and education and hereby invite all, partners, organisations and stakeholders to play a full part in promoting a better understanding of climate change and its impacts and in addressing adaptation and mitigation”. It is urgent that such a campaign specifically target the farming community on the impacts of climate change on crop pest activity. Farmers are likely pay more attention to the impacts of low rainfall and resulting drought or too much precipitation and attendant flooding and the impacts that these events have on their production. Ministries of Agriculture, through their research and extension divisions and with the collaboration of their technical assistance partners, urgently need to develop relevant programmes to inform the public in general and the farming community more specifically, on the impact of climate change on pest activity and implementable mitigating practices.

1 INTRODUCTION

One of the major constraints globally to increased food production and food security is the action of crop pests, whether native or introduced species. Oerke (2006), for example, reported global losses in several crops, varying from 50% in wheat to over 80% in cotton; for maize, rice and potatoes losses were 31, 37 and 40%, respectively. Further, according to this report, weeds generally caused the highest potential loss (34%), with animal pests and pathogens responsible for losses of 18 and 16 percent respectively. Here in the Caribbean, crop pests can be equally devastating, The recent introduction and establishment of Black Sigatoka disease of banana and plantain in the Caribbean region, for example, considered the most damaging disease of banana and plantain as well as the mostly costly to control, have resulted in so severe losses in these crops that in some countries some farmers have given up production (Pérez Vincente, 2013). Losses result from foliar damage and destruction so affecting plant growth and yield. However, the greatest loss results from premature ripening of fruit both in the field and during transport and storage. In their review of Black Sigatoka, Marín et al. (2003) indicated that losses of over 38 percent in plantain have been reported and, control activities could account for 27 percent of production costs (Etebu and Young-Henry 2011). Pérez et al. (2003) reported a four-fold increase in control costs following the appearance of the disease in Cuba in 1990 and reached USD $2.0 million in the first year following its introduction. In Brasil, Cavalcante et al. (2004) reported that banana production fell by 42% in the State of Acre between 2000 and 2001 and another 47% in 2001. The economic impact of Pink Hibiscus Mealybug, *Maconellicoccus hirsutus*, another fairly recently introduced species to this region, has been well documented (Kairo et al. 2000).

Notwithstanding that control options exist for many of these pests, the exclusion of new pests into new environments and habitats is an important management tool. While this is accomplished through effective plant quarantine systems, new pest introductions may be difficult and at times impossible to prevent.

Today, one of the major factors facilitating the movement and establishment of pests into new environments is that of climate change. While extreme weather changes and events now make front page headlines globally because of the increasing incidence of flooding, drought and heat waves in major cities where such events had only rarely occurred in the past, there is also increasing concern of the effects of changes in climate on agriculture and food security. One such concern is the impact of climate change driven or, more particularly, global warming driven movement of pest species into areas from which they had previously been unable to colonise because of adverse climatic and/or other environmental factors. Such adverse factors which population ecologists have classified as abiotic and biotic, impact on pest population growth, limiting the ability of any species to achieve full reproductive potential or maximum population levels. While climatic or abiotic factors are primarily important in this regard, they have been shown to sometimes have the opposite effect, producing more favourable conditions for the distribution, survival and establishment of pest species into new environments.

This report will first consider aspects of pest dynamics and crop interactions, report on some recent pest introductions into the region including a case study of the Pink Hibiscus Mealy bug in the Caribbean and briefly consider the impact of climate change on pests. Some suggestions for policy interventions by Governments to deal with the threat of invasive pests in relation to climate change and weather variables will then be made.

2 SOME MAJOR CROP PESTS IN THE CARIBBEAN

In the Caribbean region, many of the recent major crop pest problems have resulted from the introduction of exotic or non-native species, what are now referred to as invasive alien species (IAS). Table 1 lists some of these introduced species into the Caribbean region. In one of the first comprehensive reports for the Caribbean, Kairo et al. (2003) documented a range of IAS threats to this region; interestingly, the least number of invasive threats identified were to agriculture. Other reports (e.g. Pollard 2005; Pollard and Pegram 2004; Pollard et al 2008) have listed some specific threats to agriculture. Some pests of important crops in the region are listed in Table 2. Apart from the direct impact on agriculture such as loss in yield and impact on livelihoods, IAS may also have serious indirect impacts; Klassen et al (2004), for example, reported on threats to US-Caribbean agricultural trade. Also, are the impacts of IAS on biodiversity. For example, not only does the giant African snail cause severe loss in yield to several crops (Mead 1961; 1979; Mead and Palcy 1992; Matalavea 1997; Birat 1971; Srivastava 1973) but this pest has also been observed preying on veronicellid slugs at two sites on the island of Oahu, Hawaii (Wallace et al. 2008). This recent observation could have grave implications for native molluscan species in those countries where the giant African snail has been recently introduced and has become established.

Table 1 Some recently introduced invasive alien species (crop pests) into the Caribbean region

Arthropods and other Invertebrates	**Diseases and pathogens**
Carambola fruit fly (*Bactrocerae carambolae*)	Moko disease (*Ralstonia solanacearum*)
West Indian fruit fly (*Anastrepha obliqua*) and other Tephritid fruit flies (*e.g. Anastrepha spp.*; *Ceratitis sp.*)	Black Sigatoka disease (*Mycosphaerella fijiensis*)
Mango seed weevil (*Sternochetus mangiferae*)	Coffee Rust (*Hemileia vastatrix*)
Red Palm Mite (*Raoiella indica*)	Coconut Lethal Yellowing
Coconut Mite (*Asceria guerreonis*)	Citrus canker (*Xanthomonas campestris pv. citri*)
Coffee Berry Borer (*Hypothenemus hampei*	Citrus tristeza virus (CTV)
Khapra Beetle (*Trogoderma granarium*)	Citrus Greening (Huanglongbing)
Beet army worm (*Spodoptera exigua*)	Frosty Pod of Cacao (*Moniliophthora roreri*)
Thrips palmi	
Silverleaf or tobacco or sweet potato whitefly (*Bemesia tabaci*);	
Coconut whitefly (*Aleurodiscus pulvinatus*)	
Citrus blackfly *(Aleurocanthus woglumi)*	
Leaf-cutting ants (*Atta* spp.; *Acromyrmex* spp.)	
Africanised bee (*Apis sp*.)	
Fire ants (*Solenopsis richteri; S. invicta*)	
Bee mites (*Acarapis woodi; Varroa destructor*	
Giant African snail (*Achatina fulica*)	

Table 2 Some major introduced pests and their host crops in the Caribbean region

Crop / crop groups	Crop pests		
	Common name	**Species name**	**Casual agent**
Vegetables	Thrips: ▪ Palm thrips; Melon thrips ▪ Chilli Thrips	▪ *Thrips palmi* ▪ *Scirtothrips dorsalis*	
	▪ Whitefly	▪ *Bemesia tabaci* ▪ *B. argentifolii*	
	▪ Giant African snail	▪ *Achatina fulica*	
	▪ Pink Hibiscus Mealybug	▪ *Maconellicoccus hirsutus*	
	▪ Beet army worm	▪ *Spodoptera exguia*	
Banana and Plantain	▪ Black Sigatoka disease	▪ *Mycosphaerella fijiensis*	
	▪ Moko disease	▪ *Ralstonia solanacearum* (race 2, biovar 1)	
	▪ Panama disease (Fusarium wilt)	▪ *Fusarium oxysporum* f. sp. *cubense*	
Citrus	▪ Citrus canker		▪ *Xanthomonas axonopodis*
	▪ Huanglongbing (Citrus Greening)		▪ *Candidatus* Liberibacter asiaticus
	▪ Citrus tristeza virus (CTV)		
	▪ Brown citrus aphid	▪ *Toxoptera citricida*	
	▪ Citrus blackfly	▪ *Aleurocanthus woglumi*	

Table 2 continued

Crop / crop groups	Crop pests		
	Common name	**Species name**	**Casual agent**
Coffee	▪ Coffee berry borer	▪ *Hypothenemus hampei*	
	▪ Coffee leaf rust		*Hemileia vastatrix*
Coconut	▪ Red palm mite	▪ *Raoiella indica*	
	▪ Coconut mite	▪ *Eriophyes guerreronis*	
	▪ Lethal Coconut Yellowing		Mycoplasma-type organism
Fruit crops	▪ Tephritid fruit flies: – Carambola fruit fly – West Indian fruit fly – Mediterranean fruit fly (Medfly)	 ▪ *Bactrocera carambolae* ▪ *Anastrepha obliqua* ▪ *Ceratitis capitata*	
	▪ Mango seed weevil	▪ *Sternochetus mangiferae*	
	▪ Papaya mealybug	▪ *Paracoccus marginatus*	
Other	▪ Fire ant ▪ Water hyacinth	▪ *Solenopsis invicta* ▪ *Eichhornia crassipes*	

3 PEST DYNAMICS AND ECOLOGY

The establishment and survival of any introduced species depend on a range of factors, both biotic and abiotic, in its new habitat and the establishment of any such species to pest status is equally dependent on these factors. Simmonds and Greathead (1977) argue that while introduced species are often the more important pests in many areas, this will depend, *inter alia*, on their taxonomic grouping (mites, aphids and other sucking insects are more likely to achieve pest status), geographical area (islands as opposed to continents), crop, and means of dispersal (small species can be transported undetected on living plant material, fruits, tubers *etc*. in trade or dispersed naturally, by air currents for example).

3.1 Density dependent and density independent factors and pest population size

Population ecologists distinguish between *density dependent* and *density independent* effects which can regulate the size of the population. Density dependent effects alter the birth rate or death rate of a population as a function of the population density or size, i.e. they become more effective at high population density and less effective at low population density. Such density dependent factors may result from intra- or inter-specific competition for food, living space, etc. or as a result of the impact of natural enemies (predators and parasites). These factors change in effectiveness as the population density changes and may positively or negatively affect final population size. For example, as the pest population size grows, the effect of natural enemies will increase (more available food) to the point where there are not sufficient hosts to support the increasing natural enemy population itself. As the natural enemy population itself now decreases, the pressure on the host population is removed, so allowing its build-up once again. Studies have shown that such density dependent factors are usually the most critical factor in the regulation of populations. Density independent factors, on the other hand, impact the population irrespective of the population density or size; for example, extreme weather conditions or application of a pesticide could decimate a population whatever its size.

Figure 1 outlines some of the major factors which affect the pest status, level of damage and management actions for any species. Of particular significance for this discussion are beneficial organisms, agricultural policy and climatic conditions**.**

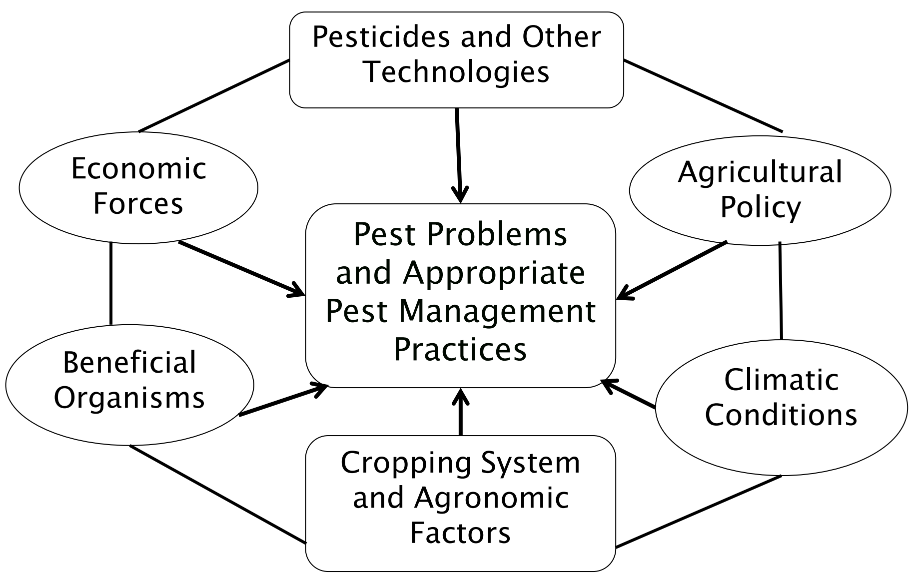

Figure 1. The many factors that affect pest status, damage and pest management (Norton and Mumford, 1993)

3.1.1 Beneficial organisms

All organisms have their natural enemies (predators and parasites and which may be referred to as beneficial organisms) which help to keep their populations in check (density dependent effects). However, when a new species with the potential to achieve pest status is introduced into a new environment, this introduced species is usually unaccompanied by its natural enemies or, any existing natural enemies in that environment are so inefficient in effecting a decline in population numbers, that a rapid build-up of the pest population results leading to the establishment of the pest and a subsequent a pest outbreak situation. However, natural enemies may be manipulated to have a greater negative impact on their pest host populations. Usually, these natural enemies are sourced from the home of origin of the introduced pest species in sufficient numbers for their release into the new ecosystem of the pest (classical biological control) or alternatively, they may be artificially reared in a laboratory and released back into the environment as a controlling agent (applied biological control). Whatever the approach, the objective is to establish the density dependent interaction between pest host and natural enemy to the detriment of the pest population.

3.1.2 Climatic Conditions

Studies on the impact of climate or weather on pest populations have traditionally been with regard to their role as density independent factors. However, climate variability is now the focus, having major impacts on pest biology, pest movement and distribution, survival and adaptation to new environments and on crop production.

3.1.2.1 What is Climate Change

According to the United Nations Framework Convention on Climate Change (1992) climate change is … a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods
(http://unfccc.int/resource/docs/convkp/conveng.pdf)

For the InterGovernmental Panel on Climate Change (IPCC, 2007), climate change is …

> "a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity and … This usage differs from that in the UNFCCC, where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods"
> (http://www.ipcc.ch/publications_and_data/ar4/syr/en/mains1.html).

Climate change and its real and potential impacts have been of major international, regional and national concern over the past two or three decades, fuelled mainly by the threats posed by global warming. For small island developing states, major concerns centre on sea level rise and the occurrence of extreme weather events. Of lesser popular concern but of major apprehension to many is the impact of climate change and climate variables on agriculture and, particularly for this discussion, on crop pests. But in developing countries, the more immediate problem is agriculture's vulnerability to climate change and the grave consequences this implies for the world's poor and hungry. Extreme weather events, viz. severe drought, storms and flooding, are expected to occur with greater frequency and have very adverse impacts on crop growth and productivity.

3.1.2.2 Climate change and crop pests

Climate and weather influence the functioning of any agro-ecosystem, affecting the growth, development and survival of crops, pest organisms and their natural enemies. Additionally, climate change and climate variability are major determining factors for the spread and distribution of crops, pests and natural enemies. Global warming together with changing rainfall patterns and other weather variables which result from climate change are most important in affecting the movement and survival of these organisms. The population dynamics of insect crop pests, for example, may be severely affected by these climate variables which may directly impact their survival, development, distribution and abundance; also, these climate variables affect host crop plants and natural enemies of the pest as well. Temperature, particularly, will affect the distribution and establishment of insect pest populations in new geographic areas which may have been previously unsuitable because of unfavourable climatic conditions, especially in higher and lower latitudinal regions as historical climate barriers are breached; the same holds for high altitudes as well. However, successful establishment of such pests will also be constrained by the presence or absence of their host plants and what control any natural enemies could have on their populations (Cammell and Knight 1992), bearing in mind that the later species may themselves be subject to climate constraints.

However, Gregory et al. (2009) and Bebber et al (2013) in recent studies reiterate that there are complex interactions between changes in climate and crops and pests. Gregory et al. (2009), for example, stated that "the extent to which crop pests and pathogens have altered their latitudinal ranges in response to global warming is largely unknown" while Bebber et al. (2013) were able to demonstrate a poleward shift of nearly 3 km yr^{-1} since 1960 after observing "hundreds of pests and pathogens". The implication of such pest movement is that more crops are likely to be at risk to increasing pest damage.

At an FAO conference on climate change and transboundary pests (FAO, 2008), several reasons were suggested for climate change resulting in a higher probability of the establishment and spread of such pests (see Box 1).

Box 1.

Climate change will result in a higher probability of entry, establishment and spread of vector-borne diseases of animals, parasites of animals with free-living life stages, and pests of plants, diseases of fish and invasive alien aquatic species for the following reasons:

- *Climate change will create winners and losers. For some animal and plant pests and diseases and invasive alien aquatic species, the climate will become more conducive and for others the meteorological conditions will become less favourable. This will result in unstable situations with a high probability of entry and establishment in areas that are presently protected by unsuitable conditions.*
- *Meteorological and related environmental circumstances may change the geographical distribution of host species, putting them in contact with animal and plant pests and diseases of related hosts to which they do not possess resistance.*
- *New animal and plant pests and diseases may emerge due to evolving selection and adaptation to new situations*

(FAO, 2008)

Any consideration of the impact of meteorological conditions on crop/pest interactions must be viewed as being more of a combination of several separate weather parameters rather than the effect of any one single factor. IPCC (2007), for example, quote several reports which suggest that CO2-temperature and CO2-precipitation interactions are "key factors" in determining plant pest damage. Of course extreme weather events like drought or flooding will have a one-off major impact on both crops and pest populations at that particular time of occurrence but the effects may persist over a long period. Also, it must be emphasised that while meteorological factors affect both crop and pest, they do not do so in the same fashion. Whether crops or pests, each requires certain conditions of water (rainfall), light and temperature for optimal growth and development, hence any change in these will have an adverse effects on their survival. Weeds, for example, can generally out-compete crop species under adverse conditions like drought. Insect pests tend to favour higher temperatures and some pest species such as, thrips and mites, proliferate under drier conditions but high levels of precipitation may cause a reduction in their populations. Good soil moisture enhances nematode populations while flooding is a deterrent to soil pests like the banana weevil (*Cosmopolites*) or burrowing rodents. Temperature, high humidity, dew, wind and air circulation patterns all influence the growth, survival and spread of crop pathogens; *e.g.* fungal spores generally require high humidity and moisture to germinate.

Given the above, how do pests (weeds, arthropods and pathogens) react to changes in climate?

a) Weeds

Weeds are opportunist plants and can adapt to a wide range of environments and soils. They can be characterised as having short life cycles, high reproductive rates and they usually respond rapidly to rainfall (Nehl 2007). The following are some responses of weeds to changing climatic factors:

- ✓ ***Increasing CO_2*** *levels could stimulate weed growth (through increased photosynthetic activity)*
- ✓ ***Increasing temperatures*** *could allow for expansion of weeds into higher latitudes/altitudes*
- ✓ *Response to* ***drought****. Any factor which causes greater environmental stress on crops may make them less competitive with weeds (also more vulnerable to pest attack)*

Apart from such positive responses of weeds to changing climate variables, weed management could also be impacted. Ziska (undated) suggested that "there are strong empirical reasons for expecting climate and/or rising CO2 to alter weed management" (http://www.climateandfarming.org/pdfs/FactSheets/III.1Weeds.pdf); for example, biological control agents could be less effective as changing climatic conditions adversely affect both target weed and natural enemies, hence there might be a need for new biological control agents; there might also be the need for new herbicides or the application of higher dosages as weed species move into new geographic areas.

b) Insects

The general consensus is that higher temperatures in temperate countries will lead to increases in insect populations and multiplication of species (increased geographic range). Alternatively, as some crops are unable to survive in areas of elevated temperatures, those insect pest populations that depend on such host crops, may also decrease. Also, increased rainfall may lead to increased flooding which could have adverse impacts on soil pests. Natural enemies may be adversely affected by changing climatic conditions and so have a lesser impact on pest populations; however, in some cases this might be enhanced e.g. entomopathogenic fungi could have a greater impact under more humid conditions.

With the anticipated increase in pest attack on crops, greater use of pesticides is envisaged. This can potentially lead to increased risks to human health, adverse environmental impacts, increased development of pesticide resistance in targeted pests, increased production costs to the grower and consequently, increased cost to consumers.

c) Pathogens

Increased rainfall may favour some pathogens and inhibit others while the spectrum of diseases in an area may change. Changing climate conditions could lead to an increase in populations of insect vectors and so impact on disease spread or vice versa. Changes in wind patterns may lead to an increase in invasive pathogenic species, For example, Rosenzweig et al. (2005) quoted several reports which indicated that the introduction of soybean rust into the US is believed to have been the result of Hurricane Ivan which hit Florida in 2004. This fungal disease has since spread rapidly in the US and it is estimated by the USDA that soybean rust would have cost American farmers US $240 million to US $2 billion/year within three to five years of its introduction. Similarly, the rapid spread of Black Sigatoka disease of banana and plantain in the Eastern Caribbean over the past decade could be resultant, in part, from hurricane activity.

Most of the predictions on the impact of climate change on crop pests arise from several models developed mainly in developed countries, so the predictive conclusions may not always apply to developing countries. However, while, in general, it appears that there will be an overall increase in pest outbreaks, establishment and spread, the precise impacts remain relatively uncertain.

3.1.2.3 Impact of climate change on crop loss and on food security

There is the view that any impacts of climate change on agriculture will be related to variabilities in local and not global climate changes; also, the rapidity and severity of change will be the most critical factors. Overall, several reports suggest that there will be a decrease in crop production (e.g. Gregory and Ingram, 2008; Nelson et al. 2009). In their report prepared for the International Food Policy Research Institute (IFPRI) analysing crop growth under climate change using a global agriculture models, Nelson et al. (2009) concluded that "agriculture and human well-being will be negatively affected by climate change. Crop yields will decline, production will be affected, crop and meat prices will increase, and consumption of cereals will fall, leading to reduced calorie intake and increased child malnutrition".

However, despite these dire predictions, the report did make several recommendations to alleviate these impacts (Box 2) but still recognised that there was no guarantee that

Box 2.

- *Design and implement good overall development policies and programmes*
- *Increase investments in agricultural productivity*
- *Reinvigorate national research and extension programs*
- *Improve global data collection, dissemination and analysis*
- *Make agricultural adaptation a key agenda point within the international climate negotiation process*
- *Recognize that enhanced food security and climate change- adaptation go hand-in-hand*
- *Support community-based adaptation strategies*
- *Increase funding for adaptation programs by at least an additional $7 billion per year*

(Nelson et al, 2009)

these investments would overcome the negative impacts of climate change. Interestingly, Gregory and Ingram (2008) concluded in their review that while changing climate is a small contributor to the current food crisis[1] it cannot be ignored.

[1] This reference to the "current" food crisis refers to the period 2005-2008

3.1.3 Agricultural policy

Implementation of certain government policies may also impact on the introduction and establishment of new pests in a country which might result from changing climate and climate variables. Such policy decisions as establishing new trade links for agricultural commodities, increased movement of peoples through the encouragement of tourism, changes in pesticide usage or promotion of agricultural diversification could all lead to new pest risks.

3.1.3.1 Establishing New Trade Links

Given the fact that trade in agricultural commodities is one of the major pathways in which pests may spread into new areas, when new trade links are established, then this represents a potential new pest pathway of entry. So if a policy is to expand trade then there is a potential for trade related invasive pest movement as well.

3.1.3.2 Increasing the tourism sector-human movement

The Caribbean is a prime destination for tourists and all CARICOM Governments continuously espouse the need for increasing the tourism industry as an important contributor to their countries' economies. In fact, for some countries like Barbados or The Bahamas, tourism is a major contributor to their GDP. There is much evidence that human movement contributes significantly to the spread of pests. When humans travel, they may deliberately carry plant material like fruits, vegetables or propagative material or even handicraft items which may harbor pests, *e.g*. coconut products as hosts for coconut mite. Humans may also act as inadvertent or deliberate vectors of pest organisms especially pathogens if they have previously been in an infected area. Anecdotal evidence, for example, suggests that Black Sigatoka disease of banana and plantain was introduced into Trinidad from Venezuela a as result of the informal/illegal trade between that latter country and the south west coast of Trinidad.

In a recent evaluation of pest pathways in the greater Caribbean area, the pest risk associated with human movement was rated as very high (Meissner et al. 2009). This high risk rating is also related to the fact that many CARICOM countries have weak plant quarantine systems, often lacking sufficient trained personnel and proper equipment to undertake efficient inspections at ports of entry.

3.1.3.3 Changes in pesticides usage

The point has been made previously that as weeds move into new geographic locations resulting from changes in climate variables, there might be the need for new herbicides or higher doses of the pesticides currently in use to effectively control these species. As part of their everyday functions, national pesticides control boards or authorities will register new pesticides or de-register some chemicals currently in use. This may be to comply with their obligations under international agreements like the Rotterdam Convention or in response to a government policy to prohibit or restrict the use of a particular chemical; or it may be in response new pest challenges. One implication of such change in pesticides use patterns is that there could be a lapse in identifying an effective chemical agent to manage a newly introduced pest problem either as a single component measure or as part of an integrated pest management programme. If a new herbicide, for example, is identified for management of a newly introduced weed species, the registration process for such a new molecule could be quite a prolonged process, as much as 4 years in some countries in the region. In the interim, the newly introduced weed species would have had the time to firmly establish itself and cause major losses to the crop or crops concerned. This same argument may be made for other pest groups besides weeds. The case of methyl bromide (MB) for phytosanitary use (fumigation) is also a good example where lack of suitable alternatives could exacerbate a pest problem. With the coming restriction and phasing out of the use of MB under the Montreal Protocol on Substances that Deplete the Ozone Layer, without suitable and effective alternatives, there will be a serious deficiency in the arsenal of national phytosanitary personnel to combat pests of phytosanitary significance which may be introduced with commodities in trade.

3.1.3.4 Agricultural diversification – promotion of new crops

Governments may have a policy of agricultural diversification, promoting the production of crops which might be new to the country or had never before been grown on a large scale. This could lead to the introduction and establishment of new pests in the country. For example, in the 1980s, Caroni (1975) Limited, then the sole sugar cane production company in Trinidad and Tobago, expanded into other crops apart from sugarcane as agricultural diversification was then a major policy of the new Government in power. The company then got involved in the production of crops such as citrus, white potato, cassava, papaya etc. What this resulted in was a host of new pest problems which the company, and the country, had never faced before like *Thrips palmi* and *Bemesia* whitefly, and cassava horn worm.

3.1.3.5 Agricultural policy, pests and climate change

While the several policy action described above, viz., the establishment of new trade links, the encouragement of tourism, changes in pesticide usage and promotion of agricultural diversification programmes, may lead to increased pest pressure by facilitating the introduction of new invasive crop pest species, medium to long term changes in climate and shorter term changes in climate variables may militate against such pest occurrences. For example, given the fickle nature of the tourism industry, it is not too far-fetched to suggest that climate change could so alter the attractiveness of some currently favoured tourist destinations as to make them no longer desirable. This would result in reduced pest risk caused by human movement.

While it was argued that promotion of agricultural diversification could lead to increased crop loss through the introduction and establishment of new pests, there is also the flip side to this as agricultural diversification could increase the resilience of agricultural systems to some of the negative consequences of extreme weather events (increased pest outbreaks, land erosion etc). Lin (2011), for example, has argued that -

> "Crop diversification can improve resilience in a variety of ways: by engendering a greater ability to suppress pest outbreaks and dampen pathogen transmission, which may worsen under future climate scenarios, as well as by buffering crop production from the effects of greater climate variability and extreme events".

Conversely, she has recognised that crop diversification policies have been slow in their implementation and has suggested why this might be so; according to her

> "Economic incentives encouraging production of a select few crops, the push for biotechnology strategies, and the belief that monocultures are more productive than diversified systems have been hindrances in promoting this strategy".

The point has been made that while many studies on the resilience of other ecosystems like forests or coral reefs have been conducted, similar studies on agroecosystems are lacking (see, Van Apeldoorn et al. 2011, for one such study, albeit on a dairy farm system). Agroecosystems are unique in that they are not natural systems in that "several functional groups of species" or "entire trophic levels" have been removed and this can affect their capacity to generate ecosystem services (Climate Justice Resource Hub; (http://www.gcu.ac.uk/climatejustice/paperdetails/?p=6103726634).

In the Caribbean context, the majority of farmers do practice some form of crop diversification or mixed cropping. Usually a mix of crops is grown dependent on the perceived market requirements at any time and on the traditional experience of the farmer. There is usually little scientific basis to the selection of crops in the mixed cropping system as currently practiced by the Caribbean farmer. For the future, research is required to identify the best blend of crops for a changing environment which will follow long term climate changes as well as more short term climate variability and weather events. For example, there is need for more drought tolerant varieties that could thrive in drought conditions resulting from increases in temperature as well as other varieties that could be more tolerant of wet conditions should rainfall periods become more extended. As small island states, many Caribbean countries may be subject to increasing levels of salt water intrusion and soil salinisation as a result of sea level rise and global warming. Researchers should be preparing for this eventuality by developing more salt tolerant varieties of commonly grown crops.

The recommendation for the development of new crop varieties to deal with harsher climatic conditions points to the wider need for the development and/or strengthening of national or regional crop improvement programmes emphasizing climate change adaptation. Where there is the required capacity, such programmes may be national in scope and, for those countries which may not have the capability to do so, a regional crop improvement programme should be established and lead by those regional institutes conducting agricultural research such as CARDI and UWI and in collaboration with national programmes. In fact, CARDI has already recognised this need and has identified the management of regional crop diversity and plant genetic resources as an important component in the development of the region's response to changing climate and its impact on regional agriculture (CARDI 2012).

Hence, if crop diversification is to be utilised as a foil to combat the impacts of climate change, this must be implemented in a planned fashion with a strong scientific underpinning and not be dependent on the whims and traditions of the farmer. Additionally, it must be emphasised that any such planned crop diversification programme must redound to the economic benefit of the farmer as well as contribute to the increased resilience of the agroecosystem.

4. ROLE OF GOVERNMENTS AND SOME REQUIRED POLICY INTERVENTIONS

Apart from national action by governments to enunciate and develop relevant policies to allow for implementation by national agricultural research institutions for the prevention of introduction and for the management of invasive pest species, there is also the urgent need for regional collaboration to mitigate the impact of a growing number of threats and actual introductions of new invasive pest species into the CARICOM or even wider Caribbean region. This is even more critical, especially given the fact that any new pest introduction will invariably and rapidly spread throughout the region. Impacts of invasive alien pests such as Coconut Lethal Yellowing or Red Palm Mite or Pink Hibiscus Mealybug on regional agricultural production underscore the necessity for regional responses to such threats (e.g. Kairo et al. 2008). The success of the regional response to the management of Pink Hibiscus Mealybug is testimony to this approach. In fact, the point has been made that preventing the introduction of invasive alien species must be a collaborative effort not only regionally but also, globally. For example, Burgiel et al. (2006) stated "To be most effective, a system of prevention measures must be international or regional in scope, and implemented at the national level via strong legislative and regulatory systems". The global impact of such transboundary pests as African desert locust, Tephritid fruit flies, Black Sigatoka and other banana diseases, cassava diseases, Khapra beetle, citrus diseases such as Huanglonbing and CTV have all warranted and benefitted from global action for their management.

4.1 Government constraints

FAO (2008) noted the inability of developing countries, in particular, to deal with transboundary pests given the range of activities required for prevention, early warning and early control in order to avoid establishment of these pests. They also noted the fragmentation of national systems among agencies and different ministries. They further concluded that:

“At present most countries have insufficient enabling legislation and resources allocated for:

- surveillance and monitoring
- border control and inspections
- expertise in risk assessment
- diagnostic tools for early detections
- expertise in diagnosis (taxonomy)
- data collection and access to information
- tools for rapid response to entry, establishment and spread
- control measures at the source of the produce”.

Where does the CARICOM region stand in relation to these identified constraints? One can say without much contradiction that most, if not all of these constraints, are applicable to the majority of CARICOM member countries. It is therefore critical that CARICOM governments initiate the necessary actions to address these constraints.

4.2 Required policy interventions

4.2.1 Review of plant protection and quarantine legislation

Several reports have identified the lack of modern plant protection and quarantine (PPQ) legislation as one of the major constraints to the delivery of up-to-date PPQ services in the Caribbean sub-region. In an FAO regional technical cooperation project (TCP/RLA/0066: Strengthening Phytosanitary Capabilities in CARICOM countries, 2000), the legal consultant to the project who drafted new plant protection legislation in keeping with modern phytosanitary principles indicated that “much of the existing legislation regulating plant protection in countries of the Caribbean region is outdated and does not reflect either modern phytosanitary concepts or agreed-upon international norms (Vapnek, 2002)”.

In another FAO report, it was stated that “One of the perceived weaknesses of the region is the lack of modern legislation to underpin the phytosanitary services of the countries” (Small 2007).

Apart from FAO, other technical assistance agencies like the Pan-American Organization/World Health Organization (PAHO/WHO) and the Inter-American Institute for Cooperation on Agriculture (IICA) have provided technical assistance to CARICOM countries for updating plant protection legislation. However, only few countries have done so. Table 3 provides the current status of plant protection legislation in CARICOM countries. Antigua and Barbuda now has the most recently proclaimed PPQ act (2012). It is incomprehensible how any country can expect to meet modern phytosanitary obligations with legislation dating as far back as 1923, even with the minor revisions in 1976, as is the case of St Kitts and Nevis. In addition, the accompanying regulations to several of the plant protection acts also need strengthening.

It is, therefore, strongly urged that the governments of those countries with outdated plant protection and quarantine legislation and inadequate regulations should make an urgent effort to enact modern legislation not only to enable the required action to safeguard their borders from foreign pests but also to comply with the international obligations of the IPPC and WTO agreements to which they are signatory. Countries may also even find it necessary to draft new legislation or amend existing legislation where applicable to deal with the expected impacts of climate change and changing weather patterns on pest introductions.

Table 3 Existing Plant Protection legislation in CARICOM countries

COUNTRY	LEGISLATION
Antigua and Barbuda	Plants Protection Act, No.18 of 2012
The Bahamas	Plants Protection Act, No.5, 1987
Barbados	Plant Protection Act, 2007
Belize	Belize Agricultural Health Authority Act, 2000
Dominica	Plant Protection and Quarantine Act, 1986
Grenada	Plant Protection Act, 1986
Guyana	Plant Protection Act No.9, 2011
Jamaica	Plant (Quarantine) Act, 1993
St. Kitts and Nevis	Plant Protection Act 2 of 1923 (Amended by Act 7 of 1976)
Saint Lucia	Plant Protection Act, No.21, 1988
Montserrat	Plant Protection Act 11 of 1941
St Vincent and the Grenadines	Plants Protection Act, 2005
Suriname	Plant Protection Ordinance, 1965
Trinidad and Tobago	Plant Protection (Amendment) Act, 2001

4.2.2 Increased support for research

Many countries have never had the capability to fully develop an effective national agricultural research capacity mainly due to the insufficiency of both human and financial resources. The formation of CARDI in 1975, probably served to exacerbate this situation as this new institute "was charged with providing for the research and development needs of the agriculture of the region as identified in national plans and policies, as well as providing an appropriate research and development service to the agricultural sector of member countries" (http://www.cardi.org/welcome-to-cardi/history/). Some countries appear to have relinquished this responsibility either wholly or partially to CARDI. However, despite the important role that CARDI has played and continues to play, countries do have the obligation to develop, to the extent that they are able to, their own research capability.

Despite these constraints, there is the recognition that more needs to be done. In a recent presentation to media personnel at the 2013 Caribbean Week of Agriculture, Dr Leslie Ramsammy, Minister of Agriculture, Guyana, lamented the poor support for research in the Caribbean indicating that "less than 0.1 % of GDP is allocated to research in the region; he also commented on the "the poor research capacity in this region" and the "poorly coordinated research agenda". It is uncertain how widespread are these latter views and whether they are representative of his CARICOM colleagues. Whatever the situation, it is critical and urgent that this perception be addressed firstly, by regional Governments who must develop or strengthen, as may be required, their own national agricultural research capacities, however limited this might be and, as well, by regional bodies engaged in agricultural research in the region. Not to be regarded as a shortcoming only in the Caribbean, it was a timely reminder by Beintema and Elliot (2009) that "Emerging challenges, such as adaptation to climate change and increasing variability of weather, water scarcity, and increased price volatility in global markets will be faced by many countries that are least able to adapt to existing stresses. This lends increasing importance to developing the human and institutional capacity in agricultural research at the national level to interact with regional and global efforts underway. A systemic approach to planning will bring universities and research institutes closer together".

And these authors further reminded policy makers "that no country is **too poor or too small** (author's emphasis) to support a national effort that is "sufficient" to gain from global knowledge".

Notwithstanding what should be an obligatory responsibility of governments in promoting and supporting national agricultural research policy and implementation, as well as in fostering collaboration at the regional level, there also needs to be greater recognition of what contribution the regional universities and other regional agricultural research and development institutions may be able to make in this regard. This is despite the view in some official quarters that, over the past few years, the Faculty of Agriculture at The University of the West Indies, for example, as the major agricultural research and teaching institution in the region, has not been living up to its mandate with respect to regional research and in providing solutions for regional problems in agriculture.

With regard to the threats of invasive pest species, national and regional research and academic institutions should be, in the first instance, critically supportive of any official governmental policy and action in identifying and mitigating the threats of such introduced species. Additionally, regional research and academic institutions must take a major, if not leading, role where countries may lack the national capability and capacity, in spearheading relevant research in the mitigation and management of introduced pest species. Preferably, such research would be in collaboration with national agricultural research institutions when or where the capability exists. Pollard (2009) indicated a possible role for academic/research institutions in the region and included the following:

- Taxonomic assistance in the identification of newly introduced species
- Research on the biology, ecology and management of invasive pest species
- Training of national plant protection and quarantine (PPQ) personnel in the identification and management of invasive species
- Training of national plant protection and quarantine (PPQ) personnel in modern plant quarantine procedures including (but not limited to) detection surveys for introduced species, inspections at ports of entry and phytosanitary treatments
- Pest risk analysis training, inclusive of pathway risk analysis, to national PPQ personnel
- Development of relevant national and/or regional databases on invasive pest species
- Assistance with the development of national pest lists
- Assistance with the development of national emergency action plans to deal with those introduced species with the grave potential to have major impacts on agro-ecosystems and natural habitats

Apart from the more easily tackled issues indicated above, there is the critical need for more research on climate change and its impact on agriculture in the Caribbean. At a presentation to the Ministry of Agriculture's Research Conference in Barbados, Pemberton (2007) emphasised that "a substantial research and development effort would be needed to create the information base which can bring about changed agricultural production and marketing systems to meet the demands of climate change. Clearly this type of development has not yet entered into the planning framework of most agricultural ministries in the region".

In attempting to analyse the impact of climate change on agriculture, Pemberton found this a challenging task and he lamented "the lack of basic historical data on rainfall, temperature and other climatic variables for CARICOM countries". However, while one may challenge Pemberton's contention of the lack of historical weather data for this region, his argument that there needs to be a greater research effort on climate change and its impact on agricultural production and marketing systems remains quite valid. Pemberton further concluded that "the investments in human and financial resources necessary to deal with the issues of climate change and agriculture will not be forthcoming unless there is a consensus among the population that climate change is occurring and that the deleterious impacts commonly spoken about globally and seen on television can really occur in the Caribbean"

While there is some merit in his view that there needs to be greater awareness by the general population of the fact of climate change and its impacts in the Caribbean, the frequency of the devastating floods that have been occurring in several Caribbean countries in recent times should well bring the point home of the fact of increasing changes in the intensity of weather events. However, his conclusion that unless there was consensus by the public that climate change is a reality, then there will be little investments in human and financial resources by the governments to deal with the problem is contentious. The implication is that governments will only respond to public pressure on this issue and this is debatable.

4.2.3 Strengthening phytosanitary capabilities

In order to prevent the introduction of new pests into a country, provisions of the International Plant Protection Convention (IPPC) and the WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) apply. These two major international agreements, of which all independent countries in CARICOM are parties, establish a framework of rules and guidelines to assist countries with the adoption, development and enforcement of sanitary and phytosanitary measures to safeguard human, animal and plant health from those organisms that may be introduced (IAS included) through trade in agricultural products or otherwise and in such a way that their negative effects on trade are limited. For example, Article IV of the IPPC not only states that all contracting parties shall establish a national plant protection organisation (NPPO) but also outlines the responsibilities of NPPOs to meet their obligations. But how successful have Caribbean governments been in the application of measures of these two agreements?

There is considerable variation in the capacity of CARICOM states to deal with the problem of introduced pest species and, further, even when there might be some national capability (e.g. regulations and infrastructure in relation to the agriculture sector generally) personnel may be insufficient or there is an inability to enforce any regulations that might be in place (Kairo et al. 2003). FAO undertook a phytosanitary capacity evaluation of all CARIFORUM member countries and while recognising strengths in each country, *e.g.* technically qualified officers, some implementation of International Standards for Phytosanitary Measures (ISPMs), collaboration, though limited, between NPPOs, the weaknesses were more telling, e.g. inadequate PPQ legislation, lack of pest diagnostic capability, lack of priority for agriculture in the national budget, no autonomous NPPO as prescribed by the IPPC, (Small 2007).

The recent introductions of Pink Hibiscus Mealybug, or Red Palm Mite or Black Sigatoka disease are all examples of the relative unpreparedness of both national governments and of the region, in general, to deal in a more proactive fashion with such pest introductions. Usually, there is a reactive response after the pest may have been established for some time before discovery.

Since any pest introduction to any one country invariably leads sooner or later to the spread throughout the region, governments may need to address this problem through a regional policy on invasive pest species. Waugh (2009) has prescribed several solutions that should be adopted to assist safe guarding the region from invasive pest species.

4.2.4 Strengthening pest risk analysis capability

One critical pillar on which any modern phytosanitary system must rest is its ability to conduct pest risk analysis (PRA). Modern phytosanitary decision making must be science-driven or be technically-justified[2] according to the IPPC and WTO SPS agreement and such science or technical justification is derived from the conduct of PRAs. To support such action, several international standards have been developed by the IPPC to assist countries in the conduct of PRAs. Of these, ISPM No. 2, 2007 - Framework for pest risk analysis, is the most fundamental of such standards and provides a set of guidelines for initiation of the PRA process to determine the risks posed by any pest whether introduced into the PRA area either directly or via a particular pathway, e.g. human movement, a particular commodity or hitchhiking. As stated in ISPM No. 2, "Pest risk analysis provides the rationale for phytosanitary measures for a specified PRA area. It evaluates scientific evidence to determine whether an organism is a pest. If so, the analysis evaluates the probability of introduction and spread of the pest and the magnitude of potential economic consequences in a defined area, using biological or other scientific and economic evidence. If the risk is deemed unacceptable, the analysis may continue by suggesting management options that can reduce the risk to an acceptable level".
(https://www.ippc.int/sites/default/files/documents//1323944382_ISPM_02_2007_En_2011-12-01_Refor.pdf)

However, despite the provision of these international standards, most CARICOM member countries have not been making adequate use of PRAs in their phytosanitary decision making or in using the results of PRAs to assist in the setting of phytosanitary regulations. Trinidad and Tobago and Jamaica have established formal PRA units within their Ministries of Agriculture while in other CARICOM countries there is some limited capacity to conduct PRAs. For more effective and transparent phytosanitary decision making in the region, it is essential that all countries establish PRA units staffed with the necessary trained personnel. But even for those countries that do not have the technical capability to do so, these countries could benefit from greater information sharing with those countries with the capability. In fact, as a policy decision for the region, governments should agree to establish a regional PRA facility with trained crop protection personnel and agricultural economists. Additionally, such a proposed unit must be well computerised and with good internet connection. Since much of PRA implementation is a desk activity, it should be relatively easy to implement such a decision.

4.2.5 Improving pest diagnostic capability

One recurring constraint to the better delivery of pest management capability in the CARICOM region is the timely identification of newly introduced pest species. The length of time that had elapsed before the Pink Hibiscus Mealybug was identified after introduction into Grenada (maybe as long as 2-3 years) only

[2] "Technically justified" is defined in Article II.1 of the IPPC Convention as: "justified on the basis of conclusions reached by using an appropriate pest risk analysis or, where applicable, another comparable examination and evaluation of available scientific information."

allowed the pest to become well established and more widely distributed. Early diagnosis would have allowed for an earlier and more effective control of the pest, and, perhaps, even eradication. As it stood, diagnosis had to be done in the UK. In fact, the region has depended for decades on the services of specialists in the UK and the USA for diagnostic services and such a service comes at a cost.

Perhaps, the time has come to implement new approaches to pest diagnosis as is being done in other countries. With the wide availability of the internet the development of distant diagnostic tools and diagnostic networks is now possible. This allows for:

- ✓ Early detection of pests (facilitates early initiation of eradication programmes)
- ✓ Accurate diagnosis by a network of specialists
- ✓ Rapid response (especially important with perishables and consignments held while awaiting final regulatory decision)

For example, such a Distance Diagnostic and Information System (DDIS) has been developed by the University of Florida/Institute of Food and Agricultural Sciences and is being utilised in Florida as a tool to enhance the capacity for screening, early detection, monitoring, pest mapping, and rapid communication to protect agriculture. According to the University of Florida website, "the DDIS provides a collaboration and communication platform for first detectors, extension specialists and diagnosticians to share information on plant insects and diseases. The system uses field data and digital media as tools for enhancement of diagnosis of plant diseases, insects, weeds, invasive species, plant management, physiology, and nutrient problems. Through interactions on the Internet between extension agents and specialists, problems can be communicated immediately and assessed". (http://ddis.ifas.ufl.edu/ddisx/home.jsp)

Perhaps, now is the time to revisit the Caribbean Invasive Species Surveillance and Information Programme (CISSIP) which was a part of the Caribbean Invasive Species Intervention Strategy (CRISIS) of which CARDI had a lead role, together with the USDA APHIS and the University of Florida. One component of this project was implementation of a Caribbean Regional Diagnostic Network with technical support provided by the University of Florida and with first phase pilot studies in Jamaica and Trinidad and Tobago as well as in Martinique and Dominican Republic. Benefits of such a programme included:

i. No need for Caribbean countries to have national specialist diagnosticians
ii. A much quicker turnaround time for pest identifications as all it takes is the time to upload a picture over the internet to an already identified specialist
iii. A reduction of costs which previously had to be paid to specialist diagnostic agencies overseas.

The outcome of this initiative to develop a Caribbean Regional Diagnostic Network is unclear but this is just the kind of effort that requires the support of regional governments to be sustainable. It is recommended that CARICOM Governments actively pursue this initiative.

4.2.6 Rationalisation of phytosanitary services

FAO (2008) had noted that national animal and plant protection infrastructure in developing countries is often fragmented among agencies and different ministries so making it difficult for the efficient delivery of services to deal with invasive pest species. In many CARICOM countries, this is quite evident with separate divisions of entomology and pathology and plant quarantine and very often each one of these is unaware of what the other is doing and it doesn't matter whether these units are in the same or separate buildings on the same compound or at different locations. Additionally, there are extension services which may have their own specialist crop protection officers who again, may be working quite independently of the crop protection unit. Then, there may be the commodity groups (banana, vegetables, rice etc.) with their expected tunnel vision, focusing attention only on their own crop groups. While this might be a somewhat exaggerated representation, it does represent the general arrangements that usually occur in many countries. And some countries have, in fact, recognised that such a situation is untenable and have enunciated a policy towards the establishment of national agricultural health and food safety agencies (NAHFSAs), where the intention is to bring under one roof all the different agencies of animal and plant health including plant and animal quarantine so as to maximise their efficiencies by consolidating several of these functions. Belize was the first CARICOM member country to do so with the establishment of the Belize Agricultural Health Agency (BAHA) in 2000.

Apart from the establishment of the NAHFSAs, there is the similar need for a complementary regional agency with a parallel mandate for the coordination of all phytosanitary matters at the regional level. Governments took a policy decision to establish the Caribbean Agricultural Health and Food Safety Agency (CAHFSA), first proposed in 1999. It was only in 2010 that the Headquarters Agreement for CAHFSA was signed between the CARICOM Secretary-General and the Government of Suriname. However, CAHFSA is yet to become operational as there is a major constraint of financing with very few countries pledging funding to date.

Governments are therefore strongly urged to implement their policies to establish their NAHFSAs as well as to do all that they can to ensure a speedy operalisation of CAHFSA.

4.2.7 Improved public education and dialogue on climate change and pests

In the 2009 Liliendaal Declaration on Climate Change and Development, CARICOM Heads of State resolved "to institute a comprehensive programme of public awareness and education and hereby invite all, partners, organisations and stakeholders to play a full part in promoting a better understanding of climate change and its impacts and in addressing adaptation and mitigation*"*.
(http://dms.caribbeanclimate.bz/webinfo/cdcfullmeta.php?id=3942&search=CARICOM)

This position by CARICOM Heads of State is most heartening as they obviously recognise the critical importance of not only raising the awareness of the public of the impacts of climate change but also, more importantly, on what might be done to mitigate its effects. This is even more urgent to target the farming community who might only be relating to such phenomena as low rainfall and resulting drought or too much precipitation and attendant flooding and the impacts that these events have on their production. The impacts of climate change on crop pest activity might be a more subtle situation which farmers might not be able to readily relate to nor appreciate. National ministries of agriculture, through their research and extension divisions and with the collaboration of their technical assistance partners urgently need to develop relevant programmes to inform the public in general and the farming community more specifically, on mitigating practices to combat the impact of climate change on pest activity. The involvement of the wider public in the effective management of the Pink Hibiscus Mealybug in the late 1990s or, more recently, of the giant African snail in several countries, is testimony of the important role that the public can play in the successful management of a major pest.

5. CONCLUSIONS

While global climate change and its actual and potential impacts have been widely investigated over the past several years resulting in an increasingly clearer understanding of this phenomenon, the more specific impacts on agriculture and, more particularly, on their effects on crop pest populations especially in tropical countries are yet to be fully understood. While there is general consensus that changes in climate will have both positive and negative effects on pest populations, there is strong evidence that there is likely to be an increase in pest outbreaks over the coming decades.

In the CARICOM and wider Caribbean region, in recent years, there has been an increase in the number of introductions of invasive pest species. The reasons for this are uncertain but while there are some more readily identifiable contributory factors such as poor or inefficient border controls and surveillance and ineffective PPQ legislation and enforcement, it is much more difficult to ascribe responsibility to the effects of climate change. However, there have been noticeable changes in the timing and intensity of the traditional wet and dry seasons in this region and this may be impacting on the increasing introductions and distribution of invasive crop pests. The impact of these seasonal changes on pest introductions and establishment require further study. The question may also be asked whether these changing weather patterns may cause any environmental stress on the host plants that may render them more vulnerable to pest attack.

Several factors affect the status, resultant host plant damage and management of pests and have been discussed above under the headings of climate conditions, beneficial organisms and agricultural policy. The former two regulate pest population dynamics and ecology with climatic factors acting in a density independent fashion and beneficial organisms acting in a density dependent manner. In the latter instance, the impact of beneficial organisms or natural enemies on host pest populations can be artificially enhanced through their manipulation in the technique of applied biological control. Successful examples of the application biological control in the Caribbean have been in the management of Pink Hibiscus Mealybug (Kairo et al. 2000) and citrus blackfly (Lopez et al. 2009).

Many developing countries do have difficulty in managing newly introduced and invasive pest species. While the reasons for this dilemma may be different from country to country, the several activities which must be implemented for the early warning, prevention and timely control or eradication of such pest introductions might be beyond the capacity and capability of many countries. Both the farmer and extension officer may lack the knowledge and tools to deal with such new pest situations. What must countries do to effectively manage these pests? This paper has identified several policy initiatives which are considered critical for governments to initiate and implement if they wish to manage invasive pest species and include:

- Updating and strengthening of plant protection legislation
- Increased support for research and extension
- Strengthening phytosanitary capabilities
- Strengthening pest risk analysis capabilities
- Improving pest diagnostic capabilities
- Rationalisation of phytosanitary services
- Improving public education and dialogue on climate change and pests

While the implementation of these measures might be difficult, but yet still achievable with the will and commitment of resources by governments, the greater challenge is to develop policies to deal with the potential threats on new pest species brought on by changing weather patterns and climate change. Also, there is the equal challenge of providing workable solutions to these threats not only by regional research institutions but also by the global research community. A great deal of research and modeling of different climate change scenarios on agriculture in general and the many expert meetings on climate change and its impact on food production and food security under the auspices on agencies like FAO (e.g. FAO 2008), IFPRI (e.g. Nelson et al. 2009), Consultative Group on International Agricultural Research (CGIAR) (e.g. Thornton 2012) and, of course, the several reports of the IPCC all point to a general consensus that increasing temperatures and shifting precipitation patterns will have an impact, whether positive or negative, on agricultural production and yields. However, there is less agreement as to how climate change will impact pests and diseases in the future.

Current predictive models suggest that pests will increase their latitudinal range with increasing temperatures, but to what extent is still uncertain (e.g. Gregory et al. 2009). Such uncertainty stems from several unknowns. For example, in their new environments, will there be new abiotic or biotic stresses impacting on pest ecology and dynamics? Will the change in distribution and survival of crop and other host plants with climate determine, to what extent, the distribution and survival of pest populations? Might there be evolutionary responses of both crops (development of pest resistance) and pest species (overcoming plant resistance; greater pathogenicity) to changing climate regimes?

The following schema for farmers and researchers and for policy/donor consideration has been adapted from Garrett (2012) who posed the question - "What do we need to understand to adapt to climate change" (to deal with emerging pest problems)? In answer, she suggested the following:

For growers

- How to adapt early warning systems for within season tactical decision making
- How to construct longer-term (season or longer) support for decision making

For researchers

- What pests to prioritise and where

For policy makers / donors

- What are the important pest problems for investment in the future
- How can financial tools buffer farmers from increased variability

This approach can be used as a template to develop a research agenda. It allows for (i) determination of what policies should be enunciated to deal with required adaptive measures for a changing climate future and what might be areas for donor support; (ii) setting a research agenda, prioritising studies on the several pest problems but, equally importantly, focusing on the farmer's concerns for short-term as well as longer-term tactical decision making with respect to the adaptive responses required as a result of changes in climate and weather variables.

Given the risks posed to the entire region even when a new pest is introduced into one country only, there is need for not only national pest emergency plans but regional plans of action to mitigate these potential pest threats. Some regional policy interventions have been suggested in this paper. For these to become operational, there needs to be a buy-in by countries together with the will and resource commitment. Already there is a vehicle which has the potential to move these initiatives into regional action in the form of CAHFSA. It is therefore critical that CARICOM Governments move with all speed to ensure that CAHFSA is made operational in the shortest possible time.

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