4 CURRENT AND POTENTIAL DISTRIBUTION AND ABUNDANCE OF PESTS

4.1 Potato Pests

4.1.1 Potato tuber moth, *Phthorimaea operculella* (Zeller 1873)

Synonym: *Gelechia terrella* (Walker 1864)
Gelechia operculella (Zeller 1873)
Gnorimoschema operculella (Zeller 1873)
Gelechia sedata (Butler 1880)
Parasia sedata (Butler 1880)

Taxonomic position: Lepidoptera, Gelechiidae

Authors: J. Kroschel, M. Sporleder, & P. Carhuapoma

Common names

Potato tuberworm, tobacco splitworm (English), Teigne de la pomme de terre (French), Polilla de la papa (Spanish), Kartoffelmotte (German)

Hosts

Phthorimaea operculella is an oligophagous pest (i.e., an insect feeding on a restricted range of food plants) of vegetable crops that belongs mainly to the family Solanaceae. Potato (*Solanum tuberosum* L.), tomato (*Lycopersicon esculentum* Mill.), and tobacco (*Nicotana tabacum* L.) are principal hosts; however, the pest also attacks eggplant (*Solanum melongena* L.), bell pepper (*Capsium annuum* L.), Cape gooseberry (*Physalis peruviana* L.), aubergine (*S. melongena* L.), and sugar beet (*Beta vulgaris* L.) of the family Chenopodiaceae. Further, wild species of the Solanaceae family, including important weeds (e.g., black night shade, *Solanum nigrum* L.), are reported hosts. In total, the host range comprises 60 species.

Detection and identification

In potato, the larva attacks all vegetative plant parts of the crop. Typical symptoms of leaf damage are mines caused by larvae feeding in the mesophyll, without damaging the upper and lower epidermis (Photo 1A). Other entry points are leaf axils and the growing points of young plants. The foliage can be completely destroyed (Photo 1B). Moths lay eggs through soil cracks on the developing tubers, which can cause high tuber damage at harvest (Photo 1C). Tuber infestation caused by first instar larvae can be hard to detect, such that even with precautionary measures infested tubers are transferred to potato stores. Characteristic piles of feces indicate infestation; inside tubers, larvae bore irregular galleries that may run into the interior of the tubers or remain directly under the skin (Photo 1D).

Photos 1. Symptoms of potato tuber moth, *Phthorimaea operculella*: (A, B) larvae infestation on leaves and (C, D) on tubers. Photos: Courtesy of CIP.

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Morphology

Egg
Size is 0.5 x 0.35 mm, whitish and turning to yellowish, deposited singly or in small batches (Photo 2A).

Larva
First instar larva is about 1 mm long; fourth instar larva reaches 9–13 mm. Color depends on the diet: in tubers larvae are whitish purple and on potato leaves purple to green (Photo 2B).

Pupa
Size is 7–8 mm long. At first, pupae are brownish in color, then turn dark brown and almost black before adults emerge (Photo 2C).

Adult
Brownish gray, with fraying on the posterior edge of the forewings and on both posterior and inner edges of the hindwings. The wings are folded to form a roof-like shape. Size of the resting moth is 7–9 mm, with a wingspan of 12–16 mm (Photo 2D).

Photos 2. The developmental stages of potato tuber moth, *Phthorimaea operculella*: (A) egg, (B) larva, (C) pupa, and (D) adults—female (left) and male (right). Photos: Courtesy of CIP.

Biology

The species is multivoltine, producing overlapping generations (i.e., all life stages are found together at the same time in potato fields or stores). After harvest, the larvae can potentially survive in volunteer potatoes, whereas eggs and pupae can survive in the soil, discarded potato piles, or even inside potato-storing facilities. For example, eggs and pupae can be found in cracks in the walls of potato stores even after the potatoes have been consumed or sold. Under favorable conditions, adult females lay up to 200 eggs—either individually or in small clusters—mainly on the underside leaf of their host plants, on potato tubers, or on the soil. Fully grown L4 larvae usually leave the feeding medium and spin a silken cocoon on plant epidermis or plant debris. Sporadically, pupation occurs inside tubers. The adult moth survives periods of extreme cold temperatures, thereby substantially reducing their metabolic rates. It is not clear whether the moth just discontinues senescence or it hibernates at certain cold temperatures. Depending on climatic conditions, the species produces 2–8 generations per year. In temperate regions of the Northern and Southern hemispheres, or subtropical elevated highlands where the cycle is interrupted by winter conditions, adults occur in spring with a peak population size at the end of the cropping period. Winter populations can be active in potato storerooms where temperature is maintained at more favorable conditions for the moth’s survival.

Temperature-dependent development

The life cycle depends strongly on prevailing temperature. According to the model established, development is possible within the temperature range of <10ºC to approximately 32ºC (see Annex 7.3.1). At 10°C, the median immature development time is about 215 days; however, with rising temperature the development time decreases and is about 17 days only at the pest’s upper temperature limit of 32°C. The lower temperature threshold for survival in larvae is around 10°C (only about 4% of the newborn survive to the adult stage). Survival rates might be higher, even at lower temperatures, if the larvae are exposed to these low temperatures intermittently. Survival in eggs and pupae is generally >85% in the range of 17°–30°C but declines gradually with decreasing or increasing temperatures outside this range—at 10°C about 78% and 65% in eggs and pupae, respectively. The lifespan of adults decreases as temperatures rise, from about 58 days at 10°C to about 8 days at 32°C. Oviposition peaks at temperatures of around 23°C, with about 164 (±40) eggs per female; 50% of the eggs are laid at this temperature within 3 days. The female fecundity rate is generally 50% (1:1 ♀:♂). Reproduction declines as temperature deviates from this optimum temperature, and the median oviposition time declines as temperature rises and extends as temperature decreases. At 10°C reproduction per female reduces to 53 (±13) eggs, whereas 50% of the eggs are laid within 9.4 days. At 32°C only 37 (±9) eggs are produced per female, and the median oviposition time shrinks to <2 days.

The models established to describe the development times, survivorship, and reproduction in the species (see Annex 7.3.1) were assembled into an overall phenology model that allows the specie's life-table parameters to be estimated according to temperature. The predicted intrinsic rate of increase (r_m) indicates that populations may establish and grow within a temperature range of 10°–32°C; the highest population growth can be expected at 29°C. At this optimum temperature population size increases potentially 14.5% per day (finite rate of increase, λ=1.145, intrinsic rate of increase, r_m=0.135)—that is, populations double within 5.1 days. These simulations indicate that *P. operculella* is adapted to a wide range of temperatures, likely due to the wide range of environmental conditions found in the Andean region where the species evolved. Therefore, the pest has been able to establish in almost all tropical and subtropical potato production areas of the world.

Means of movement and dispersal

Adults disperse in short "hopping" flights near the ground, with the aid of prevailing winds. The moths can move up to 0.25 km to infest plants or tubers, although it has been observed that they do not move from potato fields unless the field is harvested. Dispersal over long distances is on potato tubers, which has facilitated the spread of moths around the globe.

Economic impact

Potato foliage can be completely destroyed, resulting in substantial yield loss. Especially high infestations early in the season can directly affect tuber yield. There is strong correlation between leaf and consequent tuber infestation; this suggests that reducing the *P. operculella* population density during the potato-growing period is key to reducing tuber infestation at harvest. Hence, the most devastating yield losses (up to 70%) are largely a result of earlier tuber infestation in the field, generally where moths have laid eggs through soil cracks on the developing tubers, or when harvest is delayed. Potatoes in rustic stores can be damaged completely within a few months if the tubers are left untreated. Infested tubers are unsuitable not only for human consumption but also for use as seed. Infested tubers produce lower yields and initiate a fast development of a new field population. In tobacco, the moth is generally considered a minor pest; however, recently (since 2007) *P. operculella* has become a major pest in tobacco plantings in the U.S. state of North Carolina. In Mediterranean countries of North Africa (e.g., Egypt), the moth causes significant crop damage in tomato.

Geographical distribution

P. operculella originated in the tropical mountainous regions of South America, the potato's center of origin. Today it has become a global pest with distribution reported in more than 90 countries (Fig. 1). The moth occurs in almost all tropical and subtropical potato production systems in Africa and Asia, as well as those in North, Central, and South America. And though it can still be of economic significance in subtropical regions of southern Europe (e.g., Italy), the long, cold winters in temperate regions generally restrict its permanent establishment and development and hence reduce its pest status.

Africa	Algeria, Burundi, Cape Verde, Congo, DR Congo, Egypt, Cameroon, Eritrea, Ethiopia, Madagascar, Malawi, Mauritius, Morocco, Kenya, Libya, Reunion, Rwanda, Senegal, Seychelles, St. Helena, Sudan, South Africa, Tanzania, Tunisia, Uganda, Zambia, Zimbabwe
Asia	Bangladesh, China (Guizhou, Yunnan), Georgia, India (Bihar, Gujarat, Himachal Pradesh, Karnataka, Madhya Pradesh, Maharashtra, Meghalaya, Orissa, Punjab, Tamil Nadu, Uttar Pradesh, West Bengal), Indonesia (Java, Sulawesi, Sumatra), Iran, Iraq, Israel, Japan (Honshu, Kyushu, Shikoku), Jordan, Korea Republic, Lebanon, Myanmar, Nepal, Oman, Pakistan, Philippines, Saudi Arabia, Sri Lanka, Syria, Thailand, Turkey, Vietnam, Yemen
Europe	Bulgaria, Croatia, Cyprus, France, Greece, Hungary, Italy (Sardinia, Sicily, Malta), Portugal (Azores, Madeira), Romania, Russia, Serbia, Spain (Canary Islands), UK (England and Wales), Ukraine
North America	USA (Alabama, Arizona, California, Colorado, Delaware, Washington, DC, Florida, Georgia, Hawaii, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Nebraska, Nevada, New Jersey, New Mexico, New York, North Carolina, Ohio, Oregon, Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Texas, Utah, Virginia, Washington, Wisconsin)
Central America and the Caribbean	Antigua and Barbuda, Bermuda, Costa Rica, Cuba, Dominican Republic, Haiti, Jamaica, Mexico, Puerto Rico, St. Vincent and Grenadines
South America	Argentina, Bolivia, Brazil (Bahia, Goias, Minas Gerais, Parana, Rio Grande do Sul, Sao Paulo), Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela
Oceania	Australia (New South Wales, Northern Territory, Queensland, South Australia, Tasmania, Victoria, Western Australia), Fiji, French Polynesia, Guam, New Caledonia, New Zealand, Norfolk Island, Papua New Guinea

Figure 1. Geographical distribution of the potato tuber moth, *Phthorimaea operculella*. Green points indicate countries with reported pest establishment; yellow points are countries with reported occurrence in protected crops (greenhouses); and red points are georeferenced distribution data.

Phytosanitary risks

P. operculella is such a global pest today that there are few countries where the species does not represent a potential external threat to agricultural production. The pest intercepts occasionally on imported plant material in European countries. It is doubtful, however, whether the species survives severe cold winters of temperate countries, and thus phytosanitary measures in Europe are not regulated by EU law. The European Plant Protection Organisation (EPPO) does list the pest as “present, widespread” in some southern European countries (e.g., Cyprus, Greece, Malta, mainland Portugal). “Few occurrence” or “restricted distribution” is recorded in Bulgaria, Croatia, France, Georgia, Italy, Romania, Russia, Serbia, Spain, Turkey, and Ukraine. In Albania, Portugal (Azores and Madeira), and the Canary Islands (Spain), *P. operculella* is recorded as “present” but no details about its status are available. In other European countries the pest is absent or intercepts only. Russia requires that potatoes imported from the EU be free of *P. operculella*, and countries exporting potatoes to the Russian Federation, such as Belgium, carry out surveys, visual inspections, sampling, and lab confirmation to provide phytosanitary guarantee of potato shipments to be free of *P. operculella*.

In Africa, CIP carried out an assessment of the *P. operculella* distribution through extensive trapping using sex pheromones in potato fields in Ethiopia, Kenya, Rwanda, Burundi, Tanzania, and Zaire during 1987–1988. The survey revealed that the range of the pest had extended from the north into the central regions of the continent and demonstrated severity of infestations in Zaire, Burundi, and Kenya. Today the pest is known to be widespread in northern Mediterranean countries (Algeria, Egypt, Morocco, Tunisia); East Africa (Ethiopia, Kenya, Tanzania, Uganda, Rwanda); and Southern Africa. In Egypt (the Nile Delta), the moth is recognized as a significant pest in tomato as well. The moth has been reported in Cape Verde, Cameroon, DR Congo, Eritrea, Madagascar, Malawi, Mauritius, Libya, Reunion, Senegal, Seychelles, St. Helena, Sudan, Zambia, and Zimbabwe, but no detailed information about its status and distribution is available. In other African countries the presence of *P. operculella* has not been confirmed. These countries should consider *P. operculella* to be a potential threat to national agricultural production (potato and other solanaceae crops) and take into account phytosanitary risk management measures.

Risks mapping under current and future climates

Global Risks

Changes in establishment and future distribution

Figure 2 illustrates the establishment risk index (ERI) predicted for the current climate scenario (year 2000) and for a climate change scenario (year 2050) on a worldwide scale. An ERI >0.95–1 predicted for the current climate scenario corresponds well with the current referenced distribution of the pest species. However, localized or occasional distribution has also been reported from areas indicated with an ERI>0.7 (Fig. 2A). Such areas include the Columbia basin in the northern United States (Oregon, Washington, Idaho); Italy and Portugal in Europe; and South Korea in Asia. Therefore, with its wide range of temperature adaptation, *P. operculella* might establish in all potato production zones within the 10°C isotherm in the Northern and Southern hemispheres.

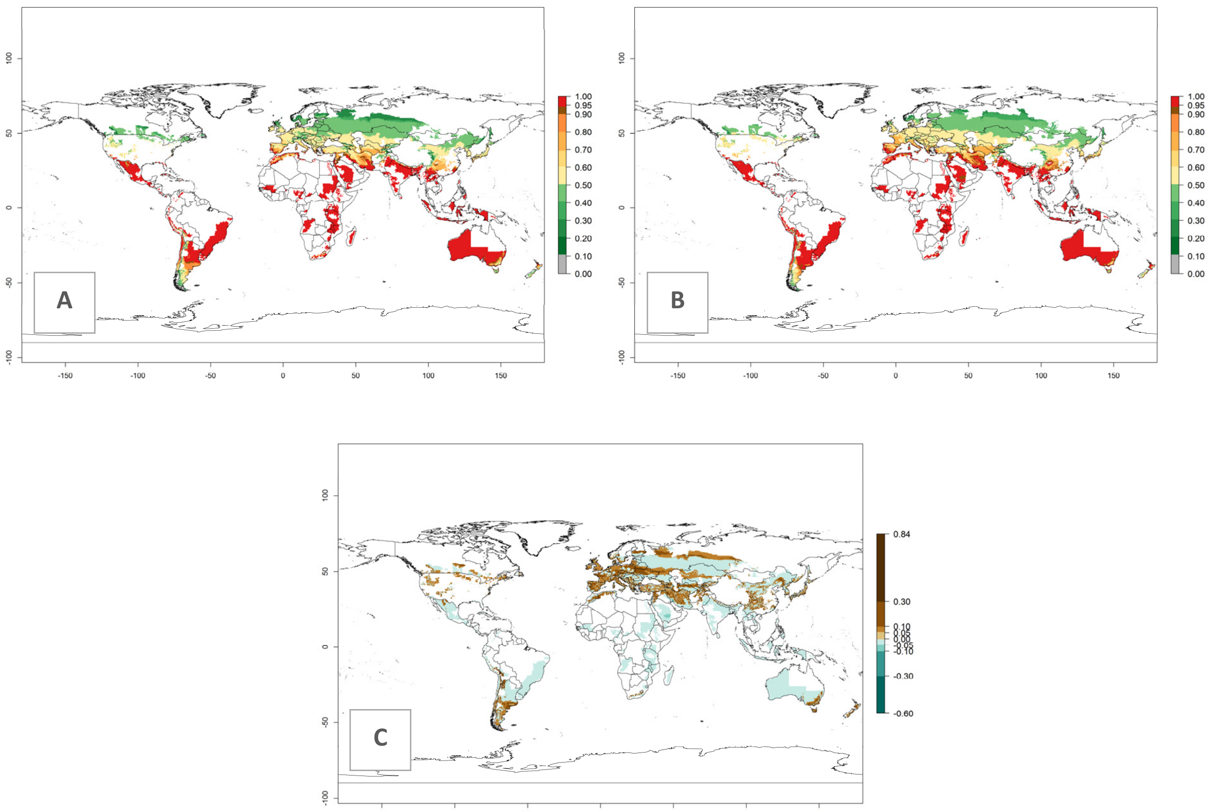


Figure 2. Changes in establishment and potential distribution of the potato tuber moth, *Phthorimaea operculella*, in potato production regions worldwide according to model predictions, using the ERI for the years 2000 (A) and 2050 (B), and changes of the ERI between 2000 and 2050 (C). An ERI>0.7 is associated with potential permanent establishment.

Current predictions on rising temperature due to climate change would suggest that the species is likely to extend its range of permanent establishment northwards and southwards in the Northern and Southern hemispheres, respectively, and into higher altitudes in tropical and subtropical mountain regions (Fig. 2B, C). In temperate regions, the risk of establishment significantly increases in the northern United States (Columbia basin), southern Europe (including France and Italy), Central Asia, New South Wales and Victoria in Australia, and in southern Chile and Argentina in South America. In all tropical mountain regions (Andes, Atlas, Alborz in Iran, and Hindu Kush-Himalaya), the boundaries for permanent establishment can be expected to move several 100 masl in altitude.

Changes in abundance

Owing to global warming, the number of generations per year and the overall abundance and activity of the pest can be expected to increase in all potato production zones worldwide (Fig. 3).

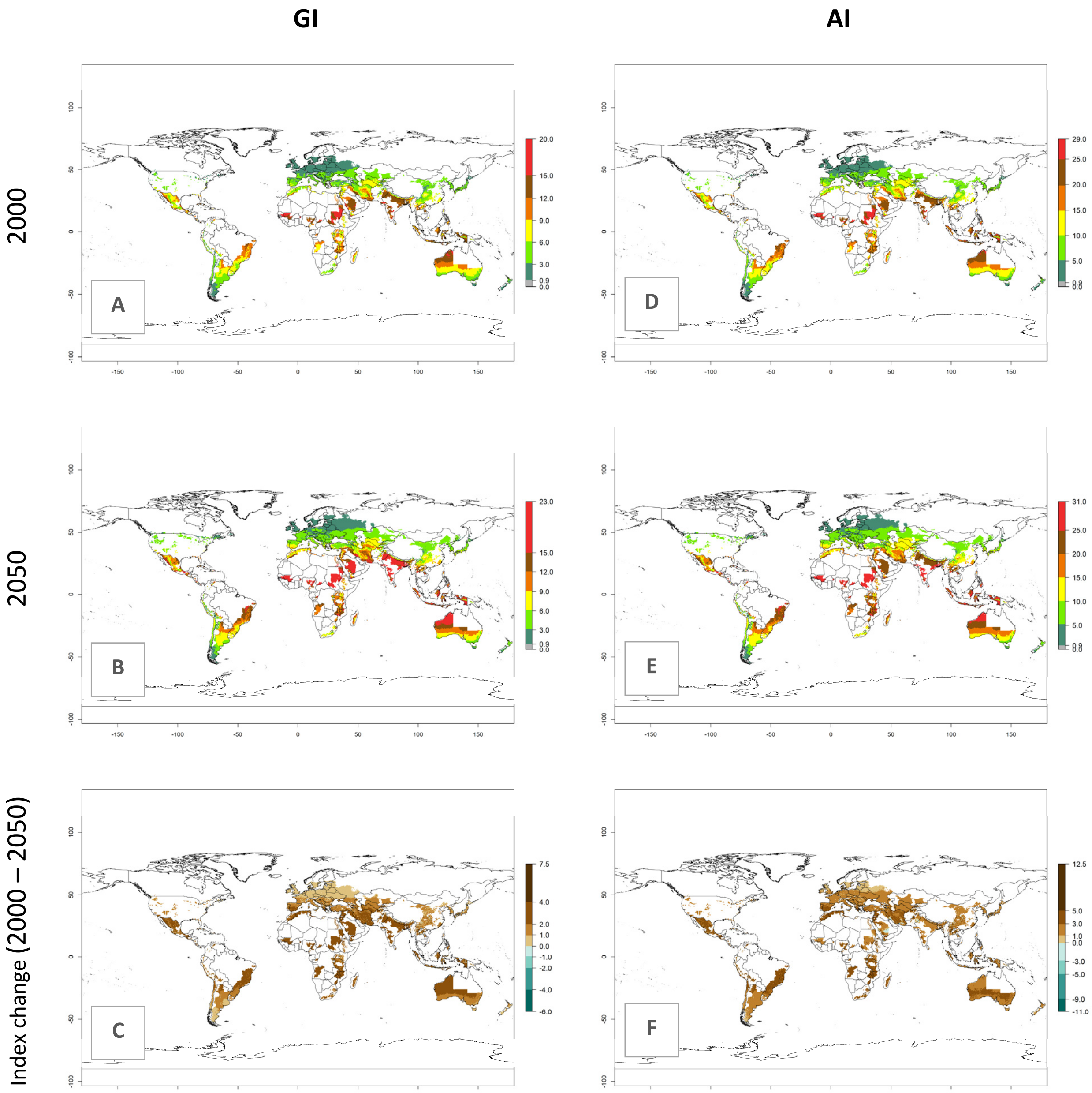


Figure 3. Changes in abundance (generation index [GI], damage potential) and activity (activity index [AI], potential population growth) of the potato tuber moth, *Phthorimaea operculella*, in potato production regions worldwide according to model predictions, using the GI (A, B) and the AI (D, E) for the years 2000 and 2050, and the absolute index change (C, F).

Regional Risks for Africa

Changes in establishment and future distribution

The likelihood of establishment of the pest is currently high in all potato-producing countries in Africa (Fig. 4), and its presence has been reported in most countries there. Climate change will not affect the *likelihood* of establishment in any of these countries, but the species might extend its range in North Africa (Morocco, Algeria, Tunisia) and in Southern Africa, especially to higher altitudes.

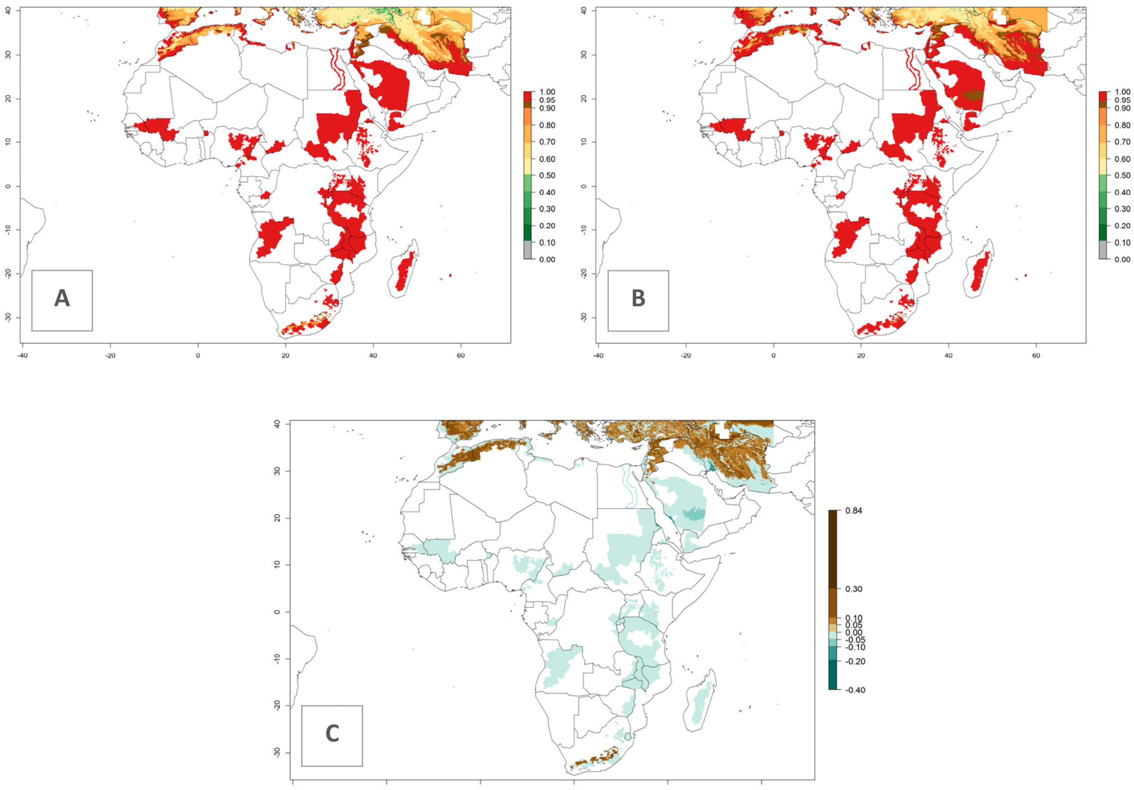


Figure 4. Changes in establishment and potential distribution of the potato tuber moth, *Phthorimaea operculella*, in potato production regions in Africa according to model predictions, using the ERI for the years 2000 (A) and 2050 (B), and changes of the ERI between 2000 and 2050 (C). An ERI>0.7 is associated with potential permanent establishment.

Changes in abundance

An increase in abundance (numbers of generations per year and activity) of *P. operculella* can be expected in all potato-producing countries in Africa (Fig. 5). The number of generations (GI) is expected to increase until the year 2050 by more than 2 generations per year in most potato production areas. This increase corresponds to an expected increase of the AI (AI>2). This means that the population size of *P. operculella* could build up within a year if population increase is not limited by other factors, and could be 100 times higher than in the year 2000. In the hot Sahel region, the GI per year could increase by more than 4 generations; however, the predicted increase in temperatures in this zone would limit moth survival and reproduction. The AI is therefore expected to increase marginally compared with other regions.

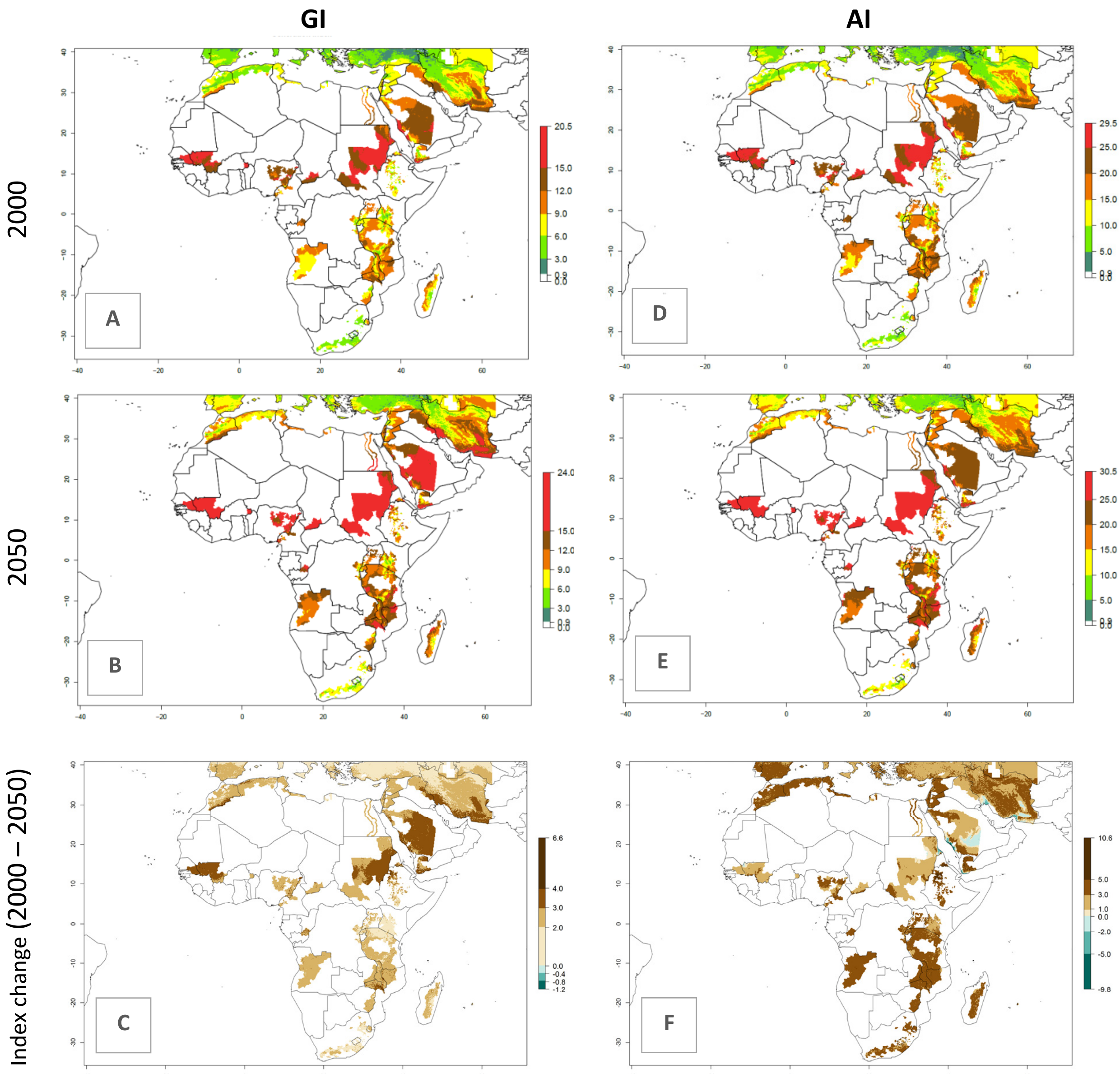
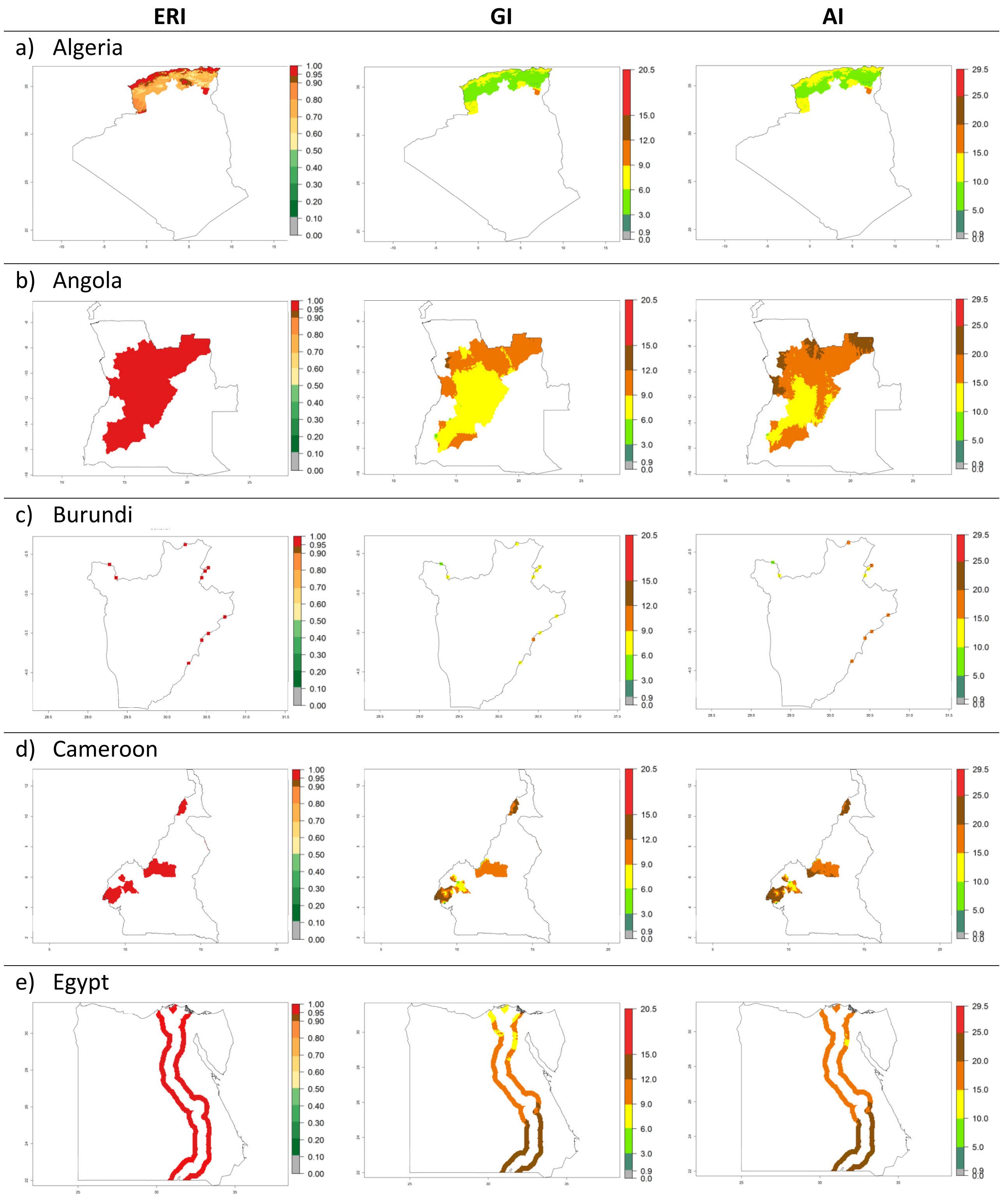


Figure 5. Changes in abundance (GI, damage potential) and activity (AI, potential population growth) of the potato tuber moth, *Phthorimaea operculella*, in African potato production systems according to model predictions, using the GI (A, B) and the AI (D, E) for the years 2000 and 2050, and the absolute index change (C, F).

Country Risk Maps

Figure 6 depicts the selected national risk maps for the countries with major potato-producing areas in North (Morocco, Algeria, Tunisia, Egypt); West (Angola, Senegal, Cameroon); East and Central (Sudan, Ethiopia, Kenya, Uganda, Rwanda, Burundi, Tanzania); and Southern (Malawi, Zimbabwe, South Africa, Madagascar) Africa. In all countries *P. operculella* has already been established or has a very high probability of establishment, with an ERI>0.95–1. In some potato production regions of North Africa, Southern Africa, and the highlands of East and Central Africa, the number of generations is lowest (with 3–6 per year) but otherwise may reach up to 12 or even 16 generations per year. Infestations of *P. operculella* are especially severe when potato is cultivated under irrigated dryland conditions; production under natural rainfall conditions reduces the abundance and population build-up.


ERI
GI
AI
a) Algeria
b) Angola
c) Burundi
d) Cameroon
e) Egypt
1.00
0.95
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
20.5
15.0
12.0
9.0
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25.0
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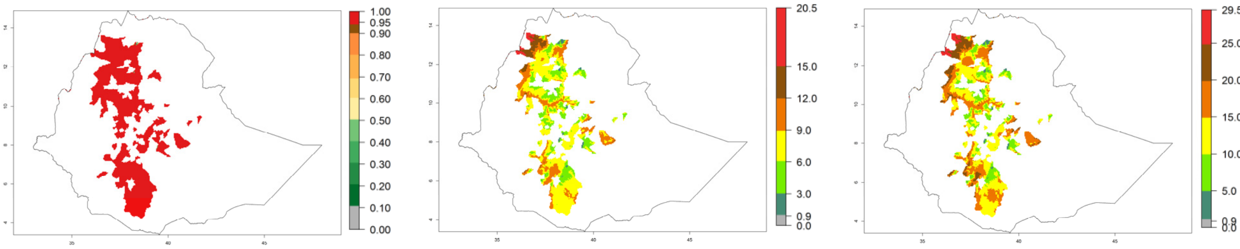
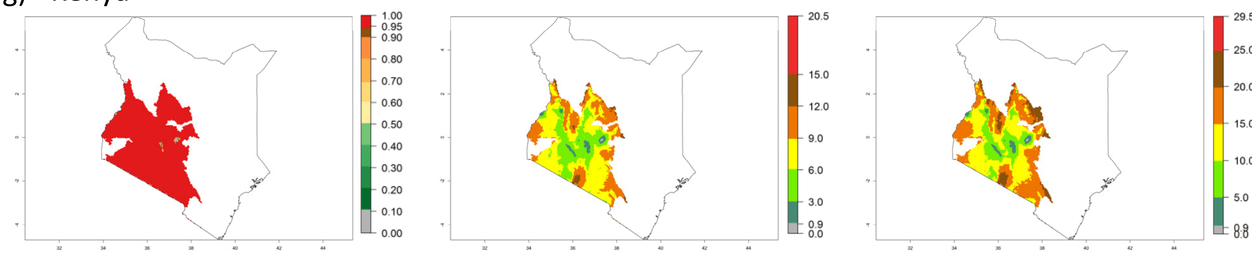
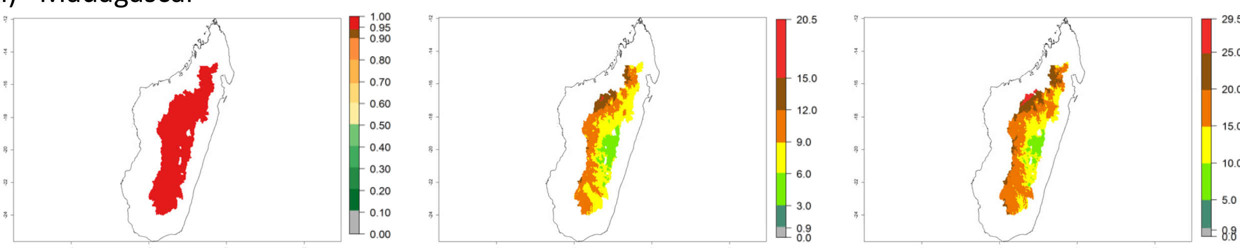
f) Ethiopia



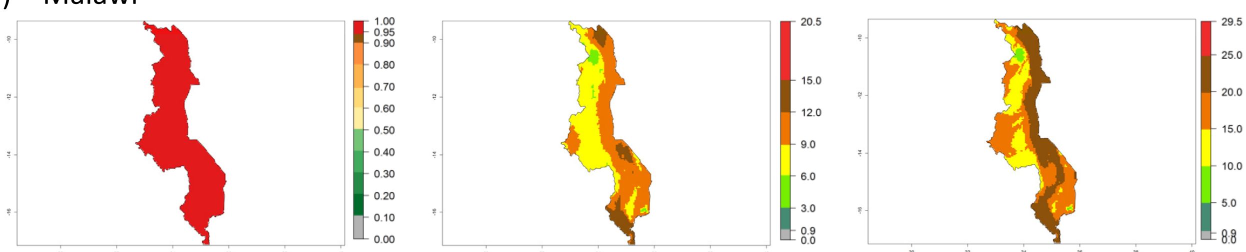
g) Kenya



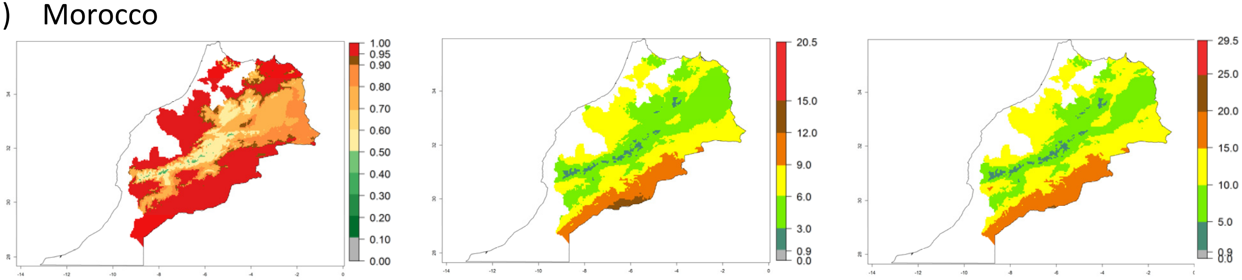
h) Madagascar



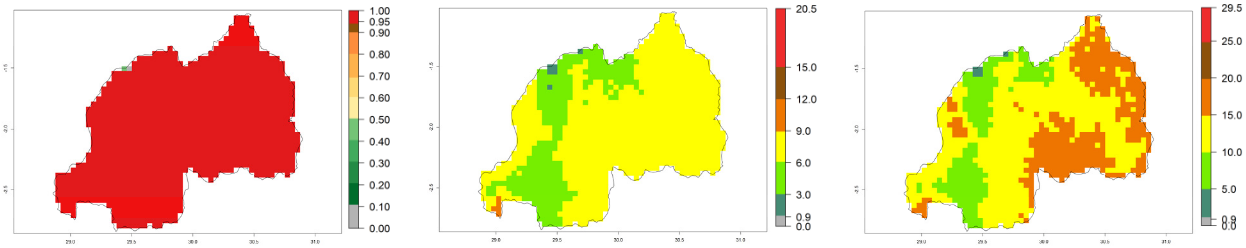
i) Malawi



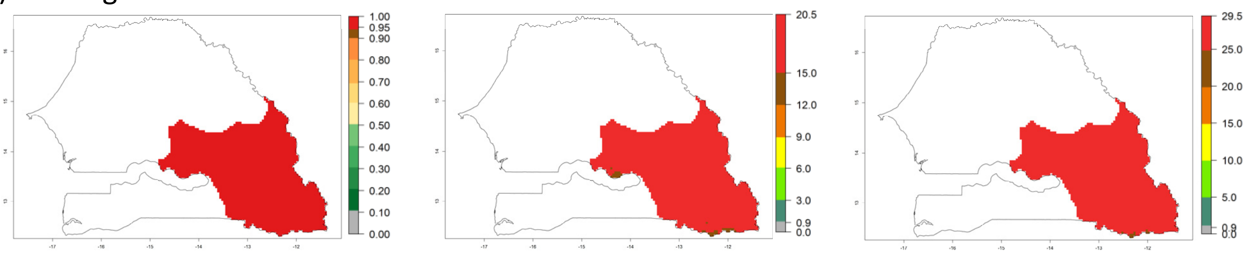
j) Morocco



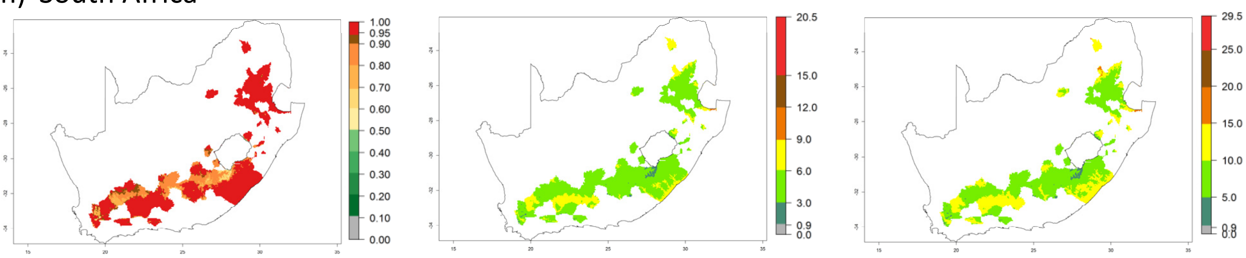
k) Rwanda



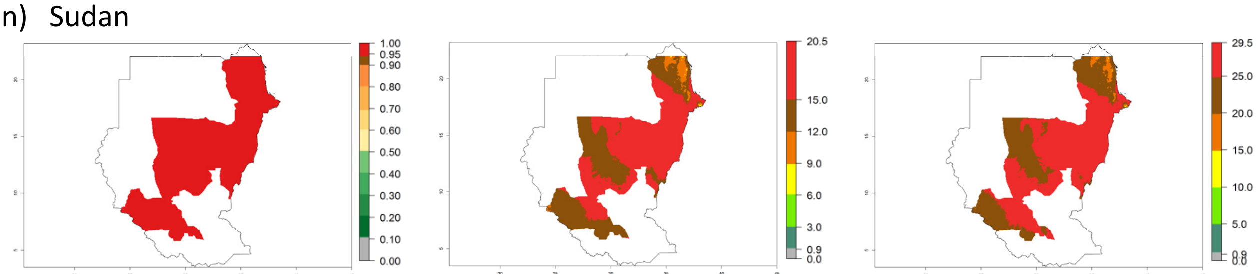
l) Senegal



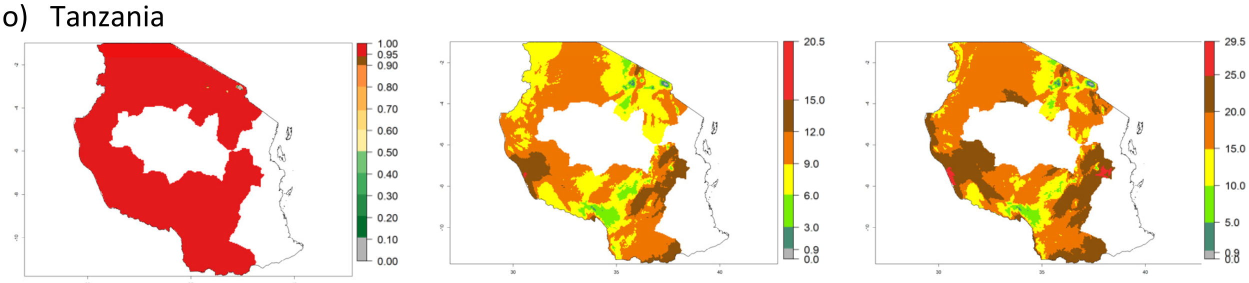
m) South Africa



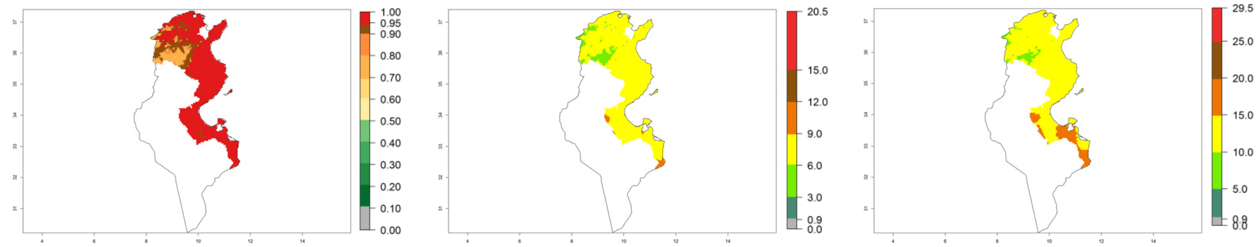
n) Sudan



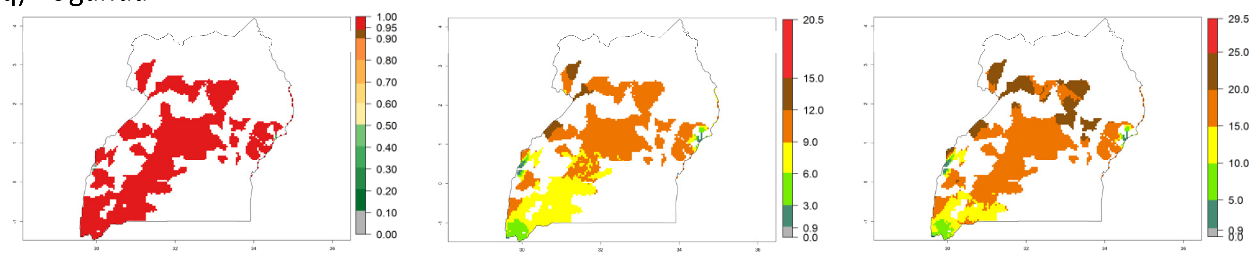
o) Tanzania



p) Tunisia



q) Uganda



r) Zimbabwe

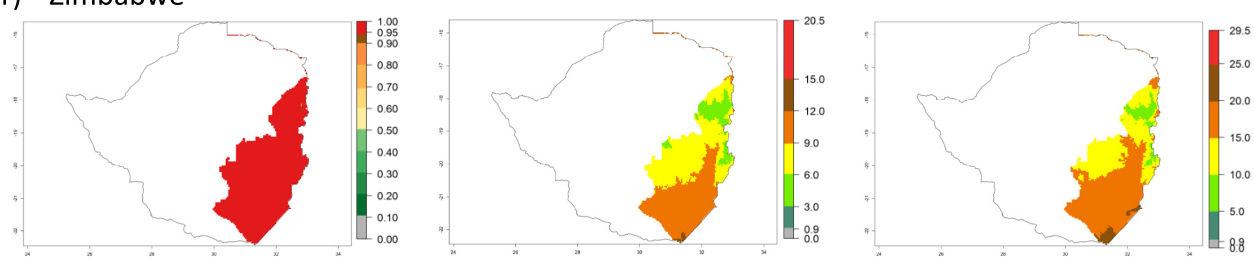


Figure 6. Establishment (ERI), abundance (GI, potential damage), and activity (AI, potential population growth) of the potato tuber moth, *Phthorimaea operculella*, in potato production regions of selected African countries according to model predictions for the year 2000. An ERI>0.7 is associated with potential permanent establishment.

Phytosanitary measures

Infestation of potato tubers with eggs or young larvae of *P. operculella* is not always easy to detect; however, shipments infested with *P. operculella* generally show certain signs that clearly confirm the presence of the pest (e.g., adult moths flying around in a ship's potato hold, or silk-cocoons visible on the tuber surface that may or may not include developing pupae). Such signs quickly confirm *P. operculella* infestation, which calls for immediate phytosanitary measures. It is recommended that countries where the pest does not yet prevail have in place a phytosanitary procedure (i.e., an officially prescribed method for performing inspections, tests, surveys, or treatments in connection with plant quarantine). These might include an official visual examination of plants and plant materials at arrival or of potatoes transported within the country to an area free of *P. operculella*. Surveys for detecting or verifying the pest can be carried out in a defined period of the year and defined potato production areas by using pheromone traps. Additional tests might confirm the presence of the moth in critical potato stocks. For example, potato tubers might be incubated in the laboratory at 24°C for several days and the samples checked for developing and emerging adults. If numerous adult moths are seen when a ship's hold is opened, prompt action is required to swat down the active moths immediately. In Europe, the EPPO's standard procedure includes an immediate application of a safe insecticide (e.g., a pyrethrin aerosol or fog). Later, the potato stocks were fumigated with methyl bromide (recommended dose is 16 g [CH_3Br] per m^3). Methyl bromide is being phased out internationally due to its ozone-depleting effects under the Montreal Protocol, and methyl bromide fumigation of potatoes has been banned in many countries since the early 2000s. Developing countries were scheduled to freeze consumption in 2002 at a 1995–1998 average and reduce consumption gradually up to 100% by 2015. Many alternatives for methyl bromide are currently used, with more alternatives in development (e.g., propylene oxide and furfural). And although potatoes should be kept refrigerated (<10°C), if feasible the temperature should be allowed to rise above 10°C before the potatoes are fumigated. To avoid phytotoxicity problems, the potatoes—especially new potatoes, which are most sensitive to *P. operculella* damage—should be thoroughly dried before fumigation. Complete degasing should be done rapidly after such treatments.

Adaptation to risk avoidance at farm level

Given the global importance of the potato tuber moth *P. operculella*, the most effective pest control is achieved through integrated pest management when a range of management methods are applied. Thereby, management techniques focus on both prevention of storage infestation and control of the pest in the field.

Crop and Field Management

Monitoring with pheromone traps. Sex pheromone-baited water or funnel (delta) traps indicate the presence of *P. operculella* in the field and store by attracting male adults. They can be used to detect the early presence of the moth in order to take adequate control.

Classical biological control. Classical biological control can be an effective strategy in all those regions where the pest has been unintentionally introduced to keep the pest population under the control threshold. Several species attacking the moth are native in South America and have been released as non-native biological control agents in several countries. Among others, the following are the most widely used parasites of the moth:

- *Apanteles subandinus* (released in Australia, Bermuda, Cyprus, India, Madagascar, Mauritius, New Zealand, South Africa, St. Helena, USA, Zambia, Zimbabwe)
- *Bracon gelechiae* (Australia, Bermuda, Chile, Cyprus, France, Hawaii, India, Malta, New Zealand, South Africa, St. Helena, Zambia, Zimbabwe)
- *Chelonus kellieae* (India, USA)
- *C. phthorimaeae* (Australia, Bermuda, Canada, Chile, Hawaii, South Africa, Yemen)
- *Copidosoma koehleri* (Australia, Bermuda, Cyprus, India, Israel, Italy, Japan, Kenya, Madagascar, Mauritius, New Zealand, Seychelles, South Africa, St. Helena, Tanzania, USA, Yemen, Zambia, Zimbabwe)
- *Copidosoma desantisi* (Australia)
- *Orgilus lepidus* (Australia, Bermuda, Cyprus, India, New Zealand, South Africa, St. Helena, Tanzania, USA, Zambia)
- *O. jennieae* (India, USA)
- *O. parcus* (Cyprus, India, New Zealand, St. Helena, USA, Zambia, Zimbabwe).

For the purpose of classical biocontrol, the most important parasitoids (*C. koehleri, A. subandinus*, and *O. lepidus*) are reared and studied at CIP-Lima, Peru. (For further merits of these species see chapter 5, sections 5.1.1–5.1.3.)

Avoid infestation of pest-free potato-growing zones. Infested seed facilitates the fast spread of the pest and is a prime source of initial infestation in potato fields. Tuber yields also are reduced from infested seed. Thus, pest-free seed tubers need to be planted.

Attract-and-kill. This is an oil formulation with the pest's sexual pheromone and contact insecticide as active ingredients and applied at a density of 2,500 droplets (100 µl)/ha in the field (1 droplet/4 m^2) to reduce the male population and hence leaf and tuber infestation. Sex pheromone-baited water traps can be used to monitor the moth activity and to determine the timing of application.

Adequate hilling. In the field, adult moths use soil cracks to reach potato tubers to lay their eggs. Infestation of potato tubers decreases with the depth in soil where tubers develop, so potato tubers need to be well covered during the whole cultivation period. This is extremely important on loamy soils, which tend to crack while drying.

Avoid dry soil conditions. Dry weather conditions favor multiplication of *P. operculella* in the field as the number of eggs laid decreases strongly with higher soil moisture; larvae drown in highly moist soil as well. The sowing date should be adjusted to avoid long periods of dry weather, especially in the weeks before harvest. If there is modest rain, sprinkler irrigation can be used to moisten the soil.

Timely and complete harvest. High tuber damage at harvest has been frequently caused by delayed harvests in combination with dry weather conditions that enable several generations to develop in the field. During dry periods, timely harvest is crucial to avoid tuber infestation. Early-maturing varieties can help to reduce the risk of infestation. Leftover tubers (volunteer plants) are frequently infested, providing a source of re-infestation and need to be removed from the field.

Storage Management

Clean storage facilities. Infested potato stores are a source of contamination for tubers stored after harvest and in surrounding fields and stores. Before potato tubers are stored, the stores need to be cleaned thoroughly. Eggs, larvae, and pupae frequently found in cracks of the walls, the soil, or in bags or boxes used for storage need to be removed. Only healthy tubers should be selected for storage.

Biological control. In Peru, a *Bacillus thuringiensis* subsp. *kurstaki* (Btk)-talcum formulation is used to protect tubers in storage against *P. operculella*. The abrasive effect of different kinds of powders (kaolin, calcium carbonate, or silica-rich sand), which is the basis of the formulation, also kills young larvae due to the powder's physical protective capacity. Potato tubers should be treated (powdered) directly after harvest and placed in storage. A *P. operculella*-specific granulovirus (Baculoviridae), called *Phop*GV, is a naturally occurring pathogen of the moth and is found in almost all parts of the world where the pest prevails. CIP has developed a *Phop*GV-biopesticide formulated in talcum that can be used to protect stored potatoes.

Attract-and-kill can be applied at a density of one droplet (100 µl)/m^2 of storage area to reduce the male population and hence tuber infestation.

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