# Evaluation of the Greek Gene Bank

Final Report: Athens, December 2012

Research supported by the Latsis Foundation

*Research Team*

Anastasios Xepapadeas (Coordinator)

Eva Kougea, Parthenopi Ralli, Sofia Spyrou, Nicolaos Stavropoulos, Vasiliki Tsiaousi, Athanasios Tsivelikas

*Participating Institutions*

Athens University of Economics and Business (Coordinating Institution)

Greek Gene Bank, Agricultural Research Center of Northern Greece, Hellenic Agricultural Organisation, "Dimitra"

Greek Biotope Wetlands – Centre

*Technical Editing*

Joan Stefan

# Contents

## EXECUTIVE SUMMARY

This study conducted an economic valuation of benefit flows associated with plant genetic resources conserved by the Greek Gene Bank (GGB) (www.eggenaueb.net), the largest ex-situ conservation program for plants in Greece.

Crop diversity stored and protected by the GGB offers multiple valuable services. For a given crop, there is a multitude of different varieties with differing shapes and colors as well as traits such as resistance to cold, tolerance to drought, or resistance to diseases, which represent a wealth of genetic potential. By combining different traits, experts and farmers have throughout the centuries enriched the variety of plants used to grow food and fodder, develop medicines and provide a number of other goods such as building materials or cloth. The current study focuses on valuing the benefits linked to seven major staple crops held at the GGB in terms of their potential future contribution to secure and enhanced food production.

Two main types of benefits which can be generated by the GGB, involving potential use of genetic resources relating to enhanced food security and increased productivity of agriculture, are analyzed in the context of this study for a time horizon of 100 years. The first type of benefits corresponds to insurance values associated with providing insurance against events that might seriously harm commercial production, while the second type, relating to applications of genetic material in order to increase farm yields, corresponds to productivity values.

An example of the role that food genetic resources can play in enhancing food security is represented by wheat and the threat posed to its supply by wheat leaf rust disease. Wheat, one of the major world staple crops which is vital to diets of a large share of the global population, stands to be affected by a disease called leaf rust. A major international effort by the Food and Agriculture Organization of the United Nations designed to prevent further spread of this leaf rust is underway. Its aim is, among others, to support the increase of wheat's genetic stock in order to help develop new resistant varieties.

Wheat is one of the major holdings of the GGB whose collection in wild wheat relatives is ranked among the top 20 on a global level. To evaluate the insurance value generated by the holdings of the GGB genetic resources of wheat, the current study examined scenarios for alternative arrival probabilities of an adverse event that will negatively affect farm yields within the next 100 years. The study estimates that services offered by the GGB as insurance for recovering losses to the value of the commercial production of wheat in Greece after a major adverse effect, could

generate benefits ranging from 13.57 to 235 million euros, in present value terms. The range of benefits depends on the assumptions regarding future risks.

Figure 1 depicts the insurance values corresponding to alternative scenarios developed in the context of this research. It is a visual representation of the insurance value generated by the GGB in supporting the development of improved varieties to counterbalance detrimental shocks to the value of commercial wheat production. It shows that insurance value attains its largest value under a pessimistic scenario where an adverse shock in wheat supply occurs 45 years into the future with a probability of arrival of such an event of 40 per cent. The lowest value of insurance services generated by the GGB corresponds to an optimistic scenario where a triggering event that negatively impacts wheat production occurs 80 years into the future with a probability of arrival 10 per cent.

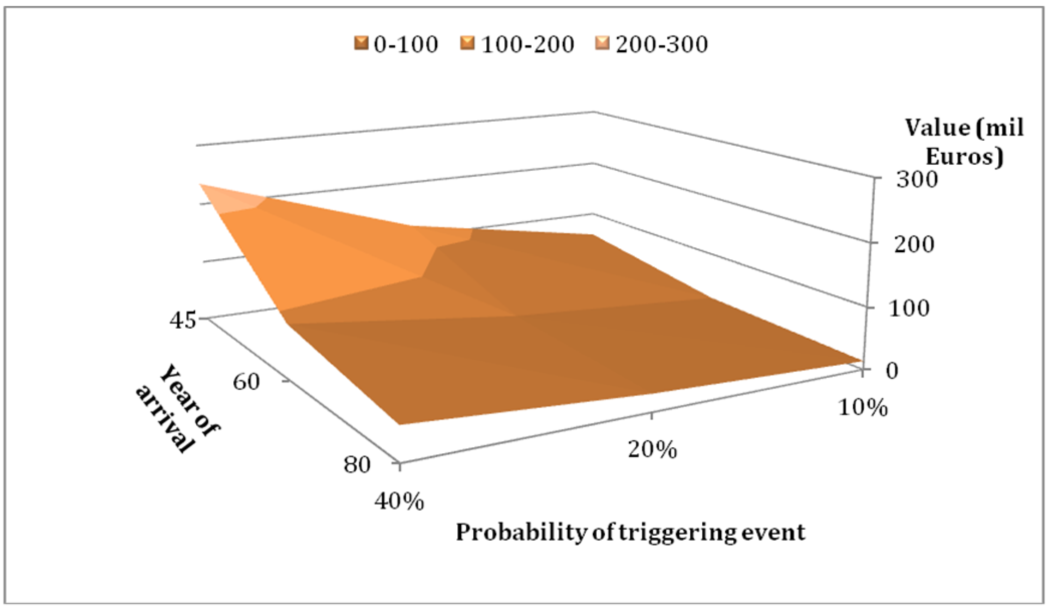



**Figure 1.** Insurance value for wheat

Aggregate insurance values generated by the seven crops of interest held by the GGB were estimated within a range of alternative scenarios of agricultural risk and potential adverse shocks in their commercial production. Possible causes of a crisis in food availability can include natural extreme events such as droughts, disease or flooding, while agricultural production can also plunge due to human-induced causes such as political or financial crisis. As climate change is considered to pose significant new uncertainties for Mediterranean agriculture, the current study also serves to indicate the potential role of the GGB in mitigating the challenges of a changing climate. Overall the study indicates that for the seven crops of interest identified within the scope of this research – namely wheat, pulses (legumes), forage and pasture grasses (vetches), beets, grapes and tobacco – the GGB may, under alternative conditions, generate insurance values ranging from 55 to 995 million euros in present value terms.

Productivity values are also positive but lower than insurance values ranging from 0.012 million euros for pulses to 5.57 million euros for sugar beets. It is worth noting however that in the design of scenarios for productivity values, conservative hypotheses concerning potential benefits of genetic material were adopted. For instance, research efforts of the Greek Cereal Institute in the 1980s resulted in the release of improved yield varieties leading to an increase in productivity of about 20 per cent. On the other hand, following the improvements in wheat varieties by the Greek Cereal Research Institute, the national wheat production increased approximately threefold in the period 1930-1970, enabling increased needs for this basic bread crop to be met successfully. In the context of the present study, a conservative assumption of a productivity increase of 10 per cent across crops has been adopted for the development of valuation scenarios.

In this study the values generated by the GGB have been estimated on a national level. Potential benefits relating to use of the GGB collection can also accrue on an international level as genetic material held by the GGB can enhance efforts to improve global agriculture. Hence if international aspects of services generated by the GGB are accounted for, the overall value of the services provided by the GGB is expected to rise significantly. This value could be even further increased by the fact that the GGB holds important stores of genetic material for wheat, the improvement of which represents a major target for a number of world regions.

In addition to not accounting for the value of the germ plasm held by the GGB on an international level, estimates of benefits in this research are also conservative because they do not account for a range of additional values which are not directly quantifiable due to a number of reasons related to their nature. It is widely recognized that biodiversity offers a host of services besides supporting enhancement of food security. Variety of crops allows people to benefit from an enriched culture and diet, and enables the conservation of traditional farming systems and preservation of rural landscapes that form part of cultural identities. The GGB additionally serves as an educational organization which helps to train young researchers in the field of genetics. Moreover, biodiversity is a natural asset recognized as contributing to maintaining healthy ecosystems able to supply services for enhanced human wellbeing. Although these are important sources of value and provide benefits complementary to insurance and productivity services, their estimation was beyond the scope of this study, whose main focus was to value the GGB using as a basis market values of agricultural production. Market values were used because, since this is the first attempt to value the GGB and therefore to set a value benchmark, the discipline provided by market data is a good basis for obtaining reliable estimates, at least for insurance and productivity values. Although the values that emerged from this analysis are subject to uncertainties, we believe that the methodology developed in this study in combination with sensitivity analysis provides a good approximation of the true underlying values, while also establishing a basis for further research to extend the valuation methodology.

Finally, a cost benefit comparison based on the results of this study confirms that the benefits of the GGB, even with the conservative estimation adopted within the current framework, significantly exceeds the costs of its operation. Thus in terms of insurance values generated by the GGB, the flow of annual equivalent values[1] were estimated to represent a minimum of 2.95 million euros whereas operating costs of the GGB currently correspond to less than 3 per cent[2] of this amount on an annual basis. Hence the present study suggests that maintaining and further developing the GGB is an economically justified strategy.

[1] Annual equivalent is used in the sense that the present value of the annual flow equals the estimated aggregate insurance value.
[2] This is based on personal communication with officers of the GGB quoting costs currently standing in the order of 100,000 euro annually.

## 1. CONTENTS OF THE GREEK GENE BANK

Founded with support of the Food and Agriculture Organization (FAO) of the United Nations, the GGB is based in Thessaloniki Greece. Over the past 30 years it has banked about 12,000 samples of cultivated plants or their wild relatives, often no longer growing in fields or in nature. Information on parts of the GGB collection is available through an online inventorying database containing European plant genetic resources of interest to researchers. The EURISCO Catalogue on National Inventories (NIs) of plant genetic data can be found at: http://eurisco.ecpgr.org/home_page.html)

The GGB conserves plant germ plasm, the living tissue from which new plants can be grown. Representing germ plasm of Greek and foreign origin held by the GGB is mostly in the form of seeds. The Bank is also designated to conserve a collection of grapevine species. Grapevine plants are grown as part of field collections maintained in Thessaloniki. Approximately half of the collection consists of indigenous wild relatives of Greek crops and the remaining half are landraces of Greek origin or breeding materials of interest to scientists.

Some of the crops in the collection have a very long history in farming, spanning thousands of years of active cultivation in the region. Additionally the Bank collection includes some rare, vulnerable or endangered species, such as for example *Medicago scutellata, Astragalus peregrinus* ssp. *Peregrine.* For some of the crops, for which Greece is said to be the geographical center of origin, the Bank holds particularly large stocks of genetic material. The current study will focus on a series of crops for which the collection of the GGB is particularly rich on a world level and which are therefore of particular interest to researchers. Among regional crops banked is first and foremost the collection of wild wheat relatives as well as legumes and grapes. Sustained plant breeding over centuries together with a naturally diverse environment have resulted in high crop diversity in these staple crops. The current study will accordingly focus on the following selection of species held by the GGB: 1) wheat and its wild relatives, 2) legumes, 3) grasses and pastures, 4) beets, 5) Brassica, 6) grapes. Table 1 lists some of the main plant genetic resources of the GGB.

**Table 1.** Plant genetic resources of the Greek Gene Bank

| Genus | Common name | Cultivated accessions | CWR accessions |
|---|---|---|---|
| *Abelmoschus* | okra | 81 (*A. esculentus*) | |
| *Aegilops* | | | 875 (*A. comosa, A. triaristata, A. lorentii,* etc.) |
| *Agropyron* | | | 21 (*A. elongatum, A. repens,* etc.) |
| *Allium* | onions and other allies | 230 (*A. cepa, A. porrum, A. sativum*) | 82 (*A. ampeloprasum, A. gutatum*, etc.) |
| *Anethum* | anise | 50 (*A. graveolens*) | |
| *Apium* | celery | 63 (*A. graveolens*) | |
| *Arachis* | groundnut | 7 (*A. hypogaea*) | |
| *Aristella* | | | 2 (*A. bromoides*) |
| *Astragalus* | | | 79 (*A. hamosus*) |
| *Avena* | oat | 59 (*A. sativa*) | 3 (*A. sterilis*) |
| *Beta* | beet | 481 (*B. vulgaris*) | 314 (*B. nana, B. maritima*) |
| *Biserrula* | | | 12 (*B. pelecinus*) |
| *Brachypodium* | | | 8 |
| *Brassica* | cabbages and kales | 220 (*B. oleraceae*) | 76 (*B. cretica*) |
| *Briza* | | | 1 (*B. media*) |
| *Calendula* | | | 2 (*C. officinalis*) |
| *Capsicum* | pepper | 220 (*C. annuum*) | |
| *Cicer* | chikpea | 222 (*C. arietinum*) | |
| *Cichorium* | | | 6 (*C. endivia*) |
| *Cistus* | | | 1 (*C. cretica*) |
| *Citrulus* | watermelon | 124 (*C. lanatus*) | |
| *Cucumis* | melon and cucumber | 383 (*C. melo, C. sativus*) | |
| *Cucurbita* | squash and pumpkin | 304 (*C. maxima, C. moschata, C.pepo*) | |
| *Cynara* | artichoke | 8 (*C. scholymus*) | |
| *Dactylis* | | | 173 (*D. glomerata*) |
| *Daucus* | carrot | 40 (*D. carota*) | 22 (*D. muricatus*) |
| *Dolichus* | hyacinth bean | 10 (*D. lablab*) | |
| *Elletaria* | cardamon | | 5 (*E. cardamomum*) |
| *Festuca* | | | 41 (*F. arundinacea*) |
| *Gossypium* | cotton | 306 (*G. hirsutum*) | |
| *Haynaldia* | | | 86 (*H. villosa*) |
| *Helianthus* | sunflower | 26 (*H. annuus*) | |
| *Hipocrepis* | | | 23 (*H. unisiliquosa*) |
| *Hordeum* | barley | 125 (*H.vulgare*) | 75 (*H. bulbosum*, etc.) |
| *Hymenocarpus* | | | 48 (*H. circinnatus*) |
| *Lactuca* | lettuce | 138 (*L. sativa*) | |
| *Lagenaria* | Bottle gourd | 43 (*L. siceraria*) | |
| *Lolium* | | | 74 (*L. perenne*) |
| *Lotus* | | | 110 (*L. corniculatus*, etc.) |
| *Luffa* | loofah | 4 (*L. acutangula*) | |

| | | | |
|---|---|---|---|
| *Lathyrus* | grass pea | 107 (*L. sativus*, *L. clymenum, L. ochrus*) | |
| *Lens* | lentil | 119 (*L. culinaris*) | |
| *Lupinus* | lupin | | 86 (*L. pilosus, L. albus,* etc.) |
| *Medicago* | | | 575 (*M. orbicularis, M. truncatula, M. arborea,* etc.) |
| *Melilotus* | | | 8 (*M. albus, M. elegans*) |
| *Mentha* | peppermint, mint | | 4 (*M. viridis, M. pulegium*) |
| *Nicotiana* | tabacco | 502 (*N. tabacum*) | |
| *Onobrychis* | | | 1 |
| *Origanum* | oregano, marjoram | | 23 (O. vulgaris, O. majorana, *O. dictamnus*, etc.) |
| *Ornithopus* | | | 26 (*O. compressus, O.pinnatus*) |
| *Oryzopsis* | | | 15 (*O. miliaceum*) |
| *Panicum* | millet | 2 (*P. miliaceum*) | |
| *Petroselinum* | parsley | 73 (*P. crispum*) | |
| *Phalaris* | | | 8 (*P. tuberosa*) |
| *Phaseolus* | bean | 919 (*P. coccineus*, *P. vulgaris*) | |
| *Phleum* | | | 12 (*P. pratense*) |
| *Pisum* | pea | 56 (*P. sativum*) | |
| *Poterium* | | | 15 (*P. sanguisorba*) |
| *Raphanus* | radish | 32 (*R. sativus*) | |
| *Salvia* | sage | | 23 (*S. officinalis, S. triloba*) |
| *Scorpiurus* | | | 38 (*S. muricatus*) |
| *Secale* | rye | 49 (*S. cereale*) | 2 (*S. montanum*) |
| *Sesamum* | sesame | 22 (*S. indicum*) | |
| *Securigera* | | | 22 (*S. securidaca*) |
| *Sideritis* | mountain tea | | 6 (*S. syriaca*, etc.) |
| *Solanum* | tomato, eggplant, potato | 580 | |
| *Sorghum* | sorghum | 5 (*S. bicolor*) | |
| *Spinacea* | spinach | 42 (*S. oleraceae*) | |
| *Thymus* | thyme | | 15 (*T. capitatus, T. vulgaris*) |
| *Trifolium* | | | 947 (*T. spumosum, T. arvense, T. stellatum*, etc.) |
| *Trigonella* | | | 63 (*T. foenum-graecum, T. balansae, etc.*) |
| *Triticum* | wheat | 261 (*T. aestivum, T. durum*) | 44 (*T. boeoticum*) |
| *Vicia* | broad bean, vetch | 321 *(V. faba, V. sativa*) | 97 (*V. cracca, V. hyrbida, V. narbonensis,* etc.) |
| *Vigna* | cowpea | 136 (*V. unguiculata*) | |
| *Vitis* | grapevine | 270 (*V. vinifera*) | |
| *Zea* | corn | 580 (*Z. mays*) | |

### Wild relatives of crop plants contained in the Greek Gene Bank

Significant categories of indigenous wild and weedy species that are close relatives or ancestors of cultivated plants held by the GGB are Cereals (*Triticum*, *Aegilops*, *Hordeum*, *Haynaldia*, *Avena*, *Secale* etc), Forages (*Trifolium*, *Medicago*, *Festuca*, *Lolium*, *Phleum* etc), Pulses (*Lens*, *Vicia*, *Lupinus* etc.), Vegetables (Cruciferae, Compositae, Umbelliferae, Liliaceae, Chenopodiaceae, Grapevine (*Vitis* spp.), Olive (*Olea* spp.), etc.

There is also a multitude of wild species directly used for human nutrition, industrial, ornamental or other uses. In this category belong certain wild species used as condiments or as decoctions (*Origanum* spp., *Ocimum*, *Majorana*, *Capparis*, *Sideritis*, etc.), aromatic plants used for the production of essential oils and perfumes (*Salvia*, *Mentha*, *Lavandula*, etc) or medicinal plants (*Digitalis*, *Ecballium*, etc).

### Landraces and old cultivars

The GGB is designated to store and conserve species originated or diversified in Greece (leguminous crops such as *Cicer*, *Lens*, *Vicia*, *Pisum* and *Lupinus*), vegetables such as *Brassica*, *Lactuca*, *Cichorium*, *Beta*, trees such as *Olea*, *Ficus* etc. and grapes, as well as species introduced in Greece centuries ago but having afterwards evolved and adapted to the local conditions (many fruit-trees such as *Malus*, *Pyrus*, *Prunus*, etc), Cereals such as *Triticum*, *Hordeum*, *Secale* etc, and vegetables such as *Phaseolus*, *Lycopersicon*, *Solanum*, *Capsicum*, etc.).

### Storage

As part of its mission the Bank works to collect, store, preserve and provide access to genetic material held in its stewardship. To help maintain seeds in a viable state, the GGB researchers undertake a number of steps. Once seed samples arrive at the Bank they are identified, cleaned and placed in a drying room where humidity levels are decreased. Once data for the seeds have been recorded, they are placed either in plain cloth or paper bags or sealed containers for long-term storage in the cold rooms. With temperatures between -5 to -20 °C, the length of time for which each collection can be stored is fixed by the biology of the seed and may last for decades.

### Wheat landraces and wild relatives

Wheat provides the structural base for world food production as it is grown on more land area worldwide than any other crop. Although it can be used as a forage crop and its grain for animal feed, the primary uses of common wheat are to make products used for human consumption. The two main commercial types of cultivated wheat are durum (*Triticum durum* L., 2n=4x=28) and bread (*Triticum aestivum* L., 2n=6x=42) wheat. The Fertile Crescent and Asia Minor are recognized as the center of diversity for wheat. Progressive adaption to a wide range of environments responding to various selection pressures including biotic, abiotic and human intervention, has resulted in characteristic intra-specific diversity and differentiation (Teshome et al., 2001) represented by many landraces with specific history and ecogeographic origin.

Wild wheat relatives also known as *Aegilops* have been very beneficial in breeding improved crops with new characteristics, particularly relating to disease resistance. Their contribution has been all the more important since wheat has developed from crossing of relatively few donor plants within this crop group, i.e. *Triticum monococcum* ssp. *boeoticum*, *Aegilops speltoides* and *Aegilops tauschii* (syn. *Aegilops squarrosa*). Besides wild wheat, two species of perennial wheat grasses, *Thinopyrum elongatum* (Host) Dewey and *Elytrigia intermedia* (Host) Nevski as well as rye (*Secale cereale* L.) (Friebe et al., 1996), have been used to improve the yields of wheat. Nonetheless, there are still major issues that wheat breeding has to address. Issues such as grain filling during increasing temperature and decreasing rainfall (expected to be exacerbated due to climate change), poor soils with low water holding capacity or aluminum and boron toxicities, growing threats of new virulence of diseases (wheat rusts, leaf blights, *Septoria* blotch, viruses, etc.), stagnating yields and a high demand for better quality, constitute the emerging challenges for wheat breeders. To this end, the potential contribution of the GGB to wheat improvement and consequently to food safety could be of particular impact for the global community, as the GGB is distinguished worldwide for the wheat landraces and wild relatives collection it maintains (Figure 2). According to Knüpffer (2009), the GGB is among the most prominent institutes worldwide, holding large collections of wheat genetic stocks with more than 600 wheat accessions, more than 500 *Aegilops* accessions and more than 50 accessions of other Triticeae.

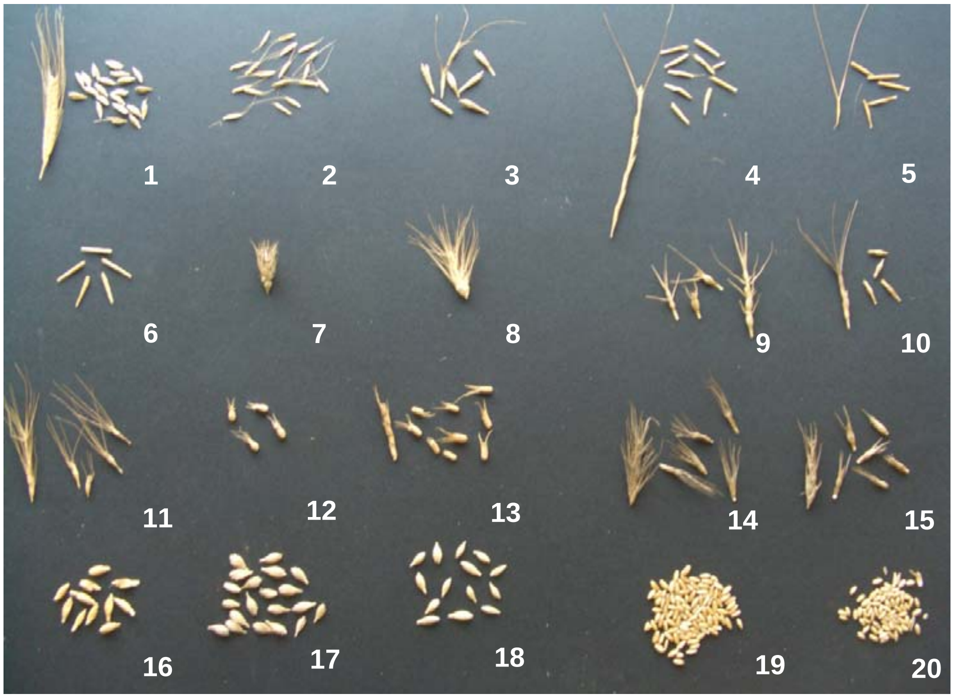



**Figure 2.** Representative accessions from wheat gene pool maintained in the GGB collection. (1) *Triticum monococcum* (diploid, genome A), (2) *Triticum monococcum* ssp. *boeoticum* (diploid, genome A), (3) *Aegilops speltoides* var. *ligustica* (diploid, genome B), (4) *Aegilops speltoides* var. *aucheri* (diploid, genome B), (5) *Aegilops caudata* (diploid), (6) *Aegilops longissima* (diploid), (7) *Aegilops ovata* (tetraploid), (8) *Aegilops umbellulata* (diploid), (9) *Aegilops unianistata* (diploid), (10) *Aegilops comosa* (diploid), (11) *Aegilops triuncialis* (tetraploid), (12) *Aegilops ventricosa* (tetraploid), (13) *Aegilops squarosa* (diploid), (14) *Aegilops kotschyi* (tetraploid), (15) *Aegilops peregrina* (tetraploid), (16) *Triticum spelta* (hexaploid, genomes A, B and D), (17) *Triticum dicoccon* var. *dicoccum* (tetraploid, genomes A and B), (18) *Triticum dicoccon* var. *farrum* (tetraploid, genomes A and B), (19) *Triticum turgidum* var. *durum* (tetraploid, genomes A and B), (20) *Triticum aetivum* (hexaploid, genomes A, B and D).

### Forage and pasture crops

Forage genetic resources play a very important role in food security and poverty alleviation, particularly in developing countries. By improving productivity of pastures used for intensive livestock production, they play a key role in supporting animal husbandry activity. Furthermore, they are extremely important environmentally as a major form of vegetation, and play a vital role in soil erosion control and carbon sequestration. Forages (herbaceous feed for herbivores) include grasses, legumes and other herbaceous species (see Figure 3).

Grasses belong to the Poaceae (Gramineae) family. Only a small fraction of less than 0.06 per cent of total species of grasses available globally are sown in pastures. The most important centers of genetic diversity for sown grasses are East Africa, Eurasia, and to a lesser extent South America. The GGB holds a large collection of more than 320 grasses accessions, constituting a representative sample of diversity of Greek grasses. Among them the most important species are *Dactylis glomerata*, *Festuca arundinacea*, *Lolium perenne, Phalaris arundinacea*, *Phleum pretense*, *Agropyron elongatum*, etc.

Legumes belong to the family Fabaceae and are important for the high quality of their forage and their ability to fix nitrogen, thereby improving soil quality. A total of approximately 18,000 species of legumes belong to about 670 to 750 genera which include important grain, pasture and forest species. The main centre of genetic diversity of temperate legumes is the Mediterranean basin (e.g., *Hedysarum coronarium*, *Lotus* spp., *Medicago* spp., *Onobrychis* spp., *Trifolium* spp.). The GGB maintains a large collection of more than 2,000 accessions of legumes, representing to a large extent the genetic variability of the principal pasture species that occur in Greek territory.

A significant number of forage species maintained in the GGB carry potential in breeding of improved crops with better nutritional quality and yield. Plant breeding in forages also aims at improving the crop's response to fertilizer as well as improving pest and frost resistance, and grazing tolerance. A striking example of their successful exploitation is the utilization of Mediterranean forage germ plasm in Australian pastures and rangelands. Over the last 30 years many annual medics (*Medicago* spp.) and subterranean clover (*Trifolium subterraneum*) from the Mediterranean basin were introduced into Mediterranean-type climatic areas of Australia, Chile, California, and South Africa. Their introduction, naturalization and diffusion has had a remarkable impact on the new environments, particularly in Australia (Cocks, 1999), where annual legumes have effectively contributed to sustaining and increasing cereal and animal production, being a basic component of ley and phase farming systems. Since the mid-1980s, more than 50 cultivars of annual legumes, mainly following germ plasm collection from Mediterranean territory, have been released in Australia for domestic use and export as seed.

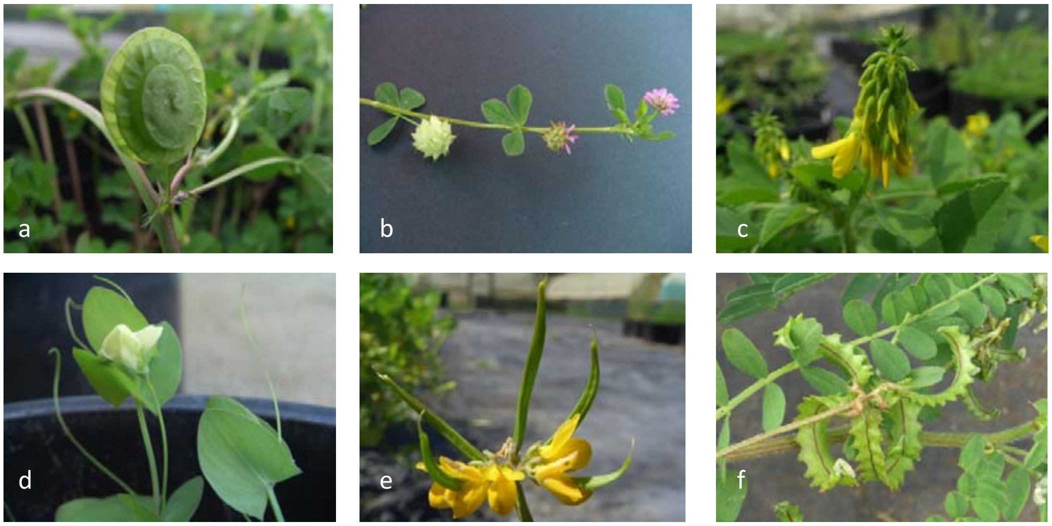



**Figure 3.** Genetic variability of pasture species maintained in GGB. a: *Medicago orbicularis*, b: *Trifolium resupinatum*, c: *Trigonella balansae*, d: *Lathyrus aphaca*, e: *Securigera securidaca*, f: *Biserulla pelecinus*

### Grain legumes

Grain legumes or pulses are an important source of nutrition and contribute a substantial part of dietary proteins in many parts of the world. Some of them, such as groundnut (*Arachis hypogaea* L.), are also important sources of edible oils. They are grown on a wide range of soil types and under varying conditions from cool temperate zones to humid tropics.

Grain legumes are particularly important crops in developing countries, as they comprise an important part of the diet as well as providing a source of livelihood for farmers. This is intensified also by the innate susceptibility of the major grain legume crops to abiotic adversities, such as soil salinity, drought and temperature extremes. In addition, there are many diseases and pests that cause unreliable and low yields to the crop. Among them, the most devastating are ascochyta blight, botrytis gray mold, anthracnose, rust, various viral infestations, as well as bruchids, spiders and leaf hoppers.

Unambiguously, encouraging crop diversity is highly strategic as it provides the basic resources to plant breeders to incorporate genetic resilience to altered environments and increased frequencies of extreme stresses, which are accompanied by increased pest and disease challenges (Street et al., 2008). The GGB maintains a great variability of grain legume landraces (Figure 4). Common bean (*Phaseolus vulgaris*), runner bean (*Phaseolus coccineus*), chickpea (*Cicer arietinum*), faba bean (*Vicia *faba*), garden pea (*Pisum sativum*), grass pea (*Lathyrus* spp.), cowpea (*Vigna unguiculata*) and lentil (*Lens culinaris*) are among the species that are best represented in the collection with potential utility in breeding. A typical example of this claim is mentioned by Duc et al. (2008) who asserted that in the screening for salinity tolerance of 504 worldwide sources of *Vicia faba* landraces, Redden et al. (2006; cited in Duc et al., 2008) ) concluded that only 16 breeding lines were tolerant, which originated from China, Greece, Egypt and Australia.

**Figure 4.** Genetic diversity among grain legume landraces maintained in the GGB

### *Brassica* genetic resources

The genus *Brassica* contains about 100 species, including cabbage, cauliflower, broccoli, brussel sprouts, turnip, various mustards and weeds (Gomez-Campo, 1999). *Brassicas* occupy third place among the various oilseed species, due to their considerable economic and nutritional value (Purty et al., 2008). They are mainly grown for oil, condiments, vegetables or fodder.

It has been generally accepted that the early evolution of the different cultivated brassicas occurred in the Mediterranean area (Ordás and Cartea, 2008). The first *Brassica* species to be domesticated was *B. rapa*, because its natural area was near the center of domestication and extended from Mediterranean regions to Central Asia in ancient times (Purty et al., 2008). The origin and evolution of cauliflower and broccoli crops also seems to be located in the Mediterranean basin, in particular the east coast, and is linked to other relatives like *B. cretica* (Gray, 1982; Gomez-Campo and Gustafsson, 1991).

The genus *Brassica* is well known for having more important agricultural and horticultural crops than any other genus (Purty et al., 2008). However, brassicas grown under field conditions are exposed to various environmental adversities, such as high temperature, cold, drought, salinity, etc. Amongst these stresses, salinity has emerged as one of the most serious factors causing a considerable reduction in growth, yield and oil production of brassica crops (Purty et al., 2008). Nevertheless, transfer of genetic information to develop salinity tolerant plants has presented a number of difficulties in practice (Purty et al., 2008). In addition, brassica crops are attacked by a wide range of insects that feed on the roots, stems, leaves, and reproductive parts of the plant. There are also several diseases that attack brassicas, such as black rot and club rot, which can substantially downgrade or even obliterate the crop.

There are also new emerging challenges in *Brassica* breeding, such as the development of effective methods for hybridization or the breeding of new varieties with modified glucosinolate content, as certain glucosinolates are associated with desirable properties in cancer prevention and crop protection. To address these issues, the exploitation of genetic diversity of *Brassica* crops and their allies constitute the most sustainable and integrated approach. Landraces and wild relatives of brassicas possess a number of useful agronomic traits which could be incorporated into breeding programs, including cytoplasmic and nuclear male sterility, resistance to diseases and insects and nematode pests, intermediate C3-C4 photosynthetic activity and tolerance for cold, salt, and drought conditions (Warwick et al., 2000). The GGB maintains a great number, more than 280 accessions, of *Brassica* landraces and wild relatives (Figure 5). These accessions reveal a high level of variability in shape, size, color, taste, earliness and other agronomic and quality traits, constituting an immense reservoir of diversity for breeding purposes.

**Figure 5.** Variability for leaf traits among *Brassica* accessions maintained in GGB

### *Beta* genetic resources

The genus *Beta* is native to Europe and adjacent areas. Sections *Nanae* (Greece) and *Procumbentes* (Canary Islands) have a limited distribution area, while wild species of section *Beta* occur along the coastline from the south of Sweden to Morocco and from the Canary island to Iran (Frese, 2002). The domestication of beets probably started in the Euphrates and Tigris region and continued in Turkey and Greece, from which cultivated beets were introduced to northern Europe (Boughey, 1981).

Since 1806, when Napoleon decreed that the beet should be grown for sugar, sugar beet has become a cash crop of worldwide importance. However, as the sugar beet was probably selected from one single cultivated population, the “White Silesian”, the genetic base of the crop is supposed to be very narrow (Frese, 2002). The narrowing of the genetic base became even more intense with the advent of modern agriculture that, simply put, increased performance of the beet but increased the reliance of this crop upon a small number of donor plants.

With a growing demand for pest and disease resistant varieties, *Beta* genetic resources are receiving increased interest from breeders who have begun to report on new sources of resistance, e.g. in *B. vulgaris* subsp. *maritima* against diseases like rhizomania and *Cercospora beticola.*

The GGB maintains a great diversity of *Beta* genetic resources with more than 800 accessions entered in the collection (Figure 6). An adequate number of these accessions have been extensively described and evaluated. In particular, within the framework of the European project "Evaluation and enhancement of *Beta* collections for extensification of agricultural production – GENRES CT95 42", funded by the Commission of the European Countries, a *Beta* core collection containing representative accessions of the collaborating countries has been developed. This core collection has been mainly evaluated in terms of disease resistance. A significant number of *Beta* wild populations and cultivated accessions maintained in the GGB were confirmed as resistant to leaf spot disease (*C. beticola*). Eventually, through the project, there is an increasing amount of evaluation data available in gene bank information systems and breeders are using this information to identify material useful for the introgression of novel genetic variation into their elite breeding pools (Frese, 2002).

**Figure 6.** Regeneration of *Beta* accessions maintained in GGB

### Grapevine genetic resources

Grapevine, *Vitis vinifera* ssp. *Vinifera*, is grown in more than 80 countries worldwide for wine production, table grapes or dried fruits (raisins). The benefits for human health are well documented as grape berries and wines contain organic compounds, such as flavonoids that have been linked to a host of beneficial properties (e.g. prevention of cardiovascular attacks, protection against various cancers and others).

The wild progenitors of grapevine are spread from West Asia to the Eastern Mediterranean region and in some cases they still exist today. However, grapevine is thought to have been domesticated in the Near East, in the area that is confined by the northern Zagros, eastern Taurus and Caucasus mountains (Zohary and Hopf, 1993; McGovern, 2003).

Grapevine crop shows an incredible biodiversity, particularly in the Mediterranean basin, accumulated over centuries and linked to local traditions. This biodiversity covers a wide area, represents an indispensable economic resource, interests the majority of small-sized farms, creates a typical rural landscape and protects the territory from natural disasters (i.e. erosion, floods, landslides, etc.). In addition, it represents the biggest potential competitive advantage of the Mediterranean viticulture in the context of the globalized wine market. However, this extreme genetic variability, already reduced by phylloxera (end of $19^{th}$ century), suffered from the advent of modern viticulture techniques, i.e. the large diffusion of few cultivars or high yielding clones on big areas. The situation is exacerbated particularly in Mediterranean countries where new viticultures adopt grapevine varieties mainly of foreign origin leading to increased exclusion of Greek varieties from farming.

Concerning the phenomenon of climate change, the loss of genetic diversity (cultivars and genotypes more adaptable) exposes the Mediterranean viticulture to higher risk of damages and makes the territories more sensitive to natural disasters.

In addition, the primary targets of grapevine breeding programs are to increase the yield and quality, and to generate cultivars well-adapted to environmental adversities such as soil factors, drought and extreme temperatures. At the same time, breeders should take into consideration the requirements for retaining highly desirable characters needed for table, raisin and principally wine production (Riaz et al., 2007). Previous breeding efforts of grapevine have led to the development of novel hybrids derived from crosses between *V. vinifera* and native American species that show pest or abiotic stress resistance. However, they are generally considered to have low fruit quality. Particularly for the wine industry, the utilization of such hybrids has been greatly limited because of the market demands to have traditional cultivars with well-documented quality and historical acceptance (Riaz et al., 2007).

Taking into consideration the extreme simplification of the varietal platform, the extinction of local genotypes and loss of genetic intra-varietal variability accumulated over centuries of grapevine cultivation as well as the market demands, the conservation of grapevine genetic diversity is an imperative need for the application of an efficient breeding strategy and for the integrated and sustainable grapevine production.

To this end, the GGB maintains as a field plantation a large collection of 270 grapevine cultivars, out of which 202 are very rare autochthonous landraces, while the remaining ones are cultivars of foreign origin (Figures 7, 8). Concerning the final product, the collection includes 209 wine-making cultivars, 60 table cultivars and 1 cultivar for raisin production. The great phenotypic variation presented by these rare native grapevine cultivars emphasizes the need for their protection, study and further evaluation, in order to promote and use the most advisable of these cultivars directly for the production of high quality wines or indirectly through the donation of desirable genes to the future programs of grapevine genetic improvement.

**Figure 7.** View of grapevine collection maintained as field plantation in the GGB

### Tobacco genetic resources

Tobacco (Nicotiana tabacum L) is mostly grown for the production of cigarettes and cigars. Its leaves are the most important raw material for the cigarette industry. Contained in many useful chemical compounds, N. tabacum is also used as insecticide, anaesthetic, diaphoretic, sedative, and emetic agent in the medicinal tradition of many countries (Rodgman & Perfetti, 2008). Therefore tobacco is regarded as a species of interest due to its potential applications through the identification of bioactive natural products from this plant (Zhong et al., 2010).


**Figure 8.** Variability on bunch traits among some rare Greek grapevine cultivars maintained in the field plantation of GGB. a: cv. Araklinos, b: cv. Xeromacherouda, c: cv. Mavrotragano, d: cv. Chlores, e: cv. Platani, f: cv. Potamisi

N. tabacum belongs to the family Solanaceae, has a tropical origin in South America and grows most efficiently in warmer climates. Although N. tabacum is a somewhat tropical plant it can be found as far north as Sweden and as far south as Australia.

N. tabacum is a main agricultural product with social and economic significance and historical roots also in the tradition of Greece. In the past, in Greece a large number of tobacco varieties were cultivated which differed in morphological characteristics, soil requirements and quality characteristics.

Although diversity of tobacco species is important to help develop new products in the agricultural or medical sectors, currently the number of species grown is relatively small (Yang et al., 2007).

The ability to develop and benefit from potential uses of the tobacco plant depends on maintaining the richness of varieties of tobacco. A wide gene pool of the Nicotiana genus can expand efforts in the tobacco industry to reduce harmful effects linked to smoking. Interest in tobacco has also grown due to recent investment in sequencing of genes of tobacco species which opens up new exciting prospects of research (Opperman et al., 2006). Use of “molecular farming" techniques is enhancing endeavors to produce beneficial proteins on a commercial scale (Fischer et al., 2004). Meanwhile whether we are able to address the decrease in tobacco varieties farmed and protect the biodiversity of tobacco will also impact our ability to develop new improved varieties with better resistance to major diseases of the crop (Murphy et al., 1987). These points highlight the need for continued effort to preserve genetic resources of this crop.

The GGB holds a large collection of more than 480 accessions of N. tabacum, constituting a fair sample of genetic variability available in Greece in recent times. Research has taken place in order to investigate the existing variability through morphological characterization of a representative sample of tobacco collections grown in Greece, during the long tradition of the particular crop. The results indicated high phenotypic variability between the studied collections (Figure 9), which were found to belong to oriental type (sun-cured), which is the oldest and most important type of tobacco cultivar in Greece, and are expected to contribute to the increase of information among plant breeders in order to efficiently improve new tobacco cultivars. These new cultivars will be characterized by disease resistance, eligible plant morphological development and cured leaf quality, as well as production of reduced harmful components of tobacco products and high quality of technological traits.

**Figure 9.** Variability in the shape of the leaf: top left: narrow elliptical blade, top right: broad elliptical blade and on the position of inflorescence among tobacco accessions, bottom left: upwards the leaves of the peak, bottom right: between the leaves of the peak

## 2. CROP GENETIC DIVERSITY: THREATS AND BENEFITS

### Introduction

Genetic diversity is one of the main components of biological diversity; according to the definition provided by the Convention on Biological Diversity, biological diversity is “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems”, whereas in the same text, genetic resources are defined as "genetic material of actual or potential value”.

It is widely recognized that all levels of biological diversity (hereafter called biodiversity for short), from genetic and species to ecosystems, contribute to maintenance of processes that provide a range of fundamental goods and services (ecosystem services) that support human existence, health, wellbeing, and livelihoods (Millennium Ecosystem Assessment, 2005; Kumar (TEEB), 2010).

Agricultural biodiversity is among the earth’s most important resources. The synthetic account of the Second Report on the State of the World’s Plant Genetic Resources for Food and Agriculture (FAO, 2010) states that the genetic diversity of grains, legumes, vegetables and fruits that we grow and eat – referred to as plant genetic resources for food and agriculture – are the foundation of food production, and the biological basis for food security, livelihoods and economic development

### Threats to genetic diversity

According to the Millennium Ecosystem Assessment (2005, Chapter 26, Cultivated Systems), since 1960 there has been a fundamental shift in the pattern of intra-species diversity in farmers’ fields in some regions and farming systems as a result of the Green Revolution. For major cereal crops, the germ plasm planted by farmers has shifted from locally adapted and developed populations (landraces) to more widely adapted varieties produced through formal breeding systems (modern varieties).

This is also stipulated in Global Biodiversity Outlook 3 (Secretariat of the Convention on Biological Diversity, 2010) which stresses that genetic diversity is being lost in natural ecosystems and in systems of crop and livestock production. While this decline is of concern for many reasons, there is particular anxiety about the loss of diversity in the varieties and breeds of plants used to sustain human livelihoods.

According to the Commission on genetic resources for food and agriculture (http://www.fao.org/docrep/012/al384e/al384e00.pdf), plant genetic diversity is threatened by "genetic erosion", a term that describes the loss of individual genes and of combinations of genes, such as those found in locally adapted landraces. The main cause of genetic erosion, according to FAO's *State of the World's Plant Genetic Resources for Food and Agriculture* (FAO, 2010), is the replacement of local varieties by modern varieties. As old varieties in farmers' fields are replaced by newer ones, genetic erosion frequently occurs because the genes found in the farmers' varieties are not all contained in the modern variety. In addition, the sheer number of varieties is often reduced when commercial varieties are introduced into traditional farming systems. Other causes of genetic erosion include the emergence of new pests, weeds and diseases, environmental degradation, urbanization and land clearing through deforestation and bush fires.

Moreover, Global Biodiversity Outlook 3 (Secretariat of the Convention on Biological Diversity, 2010) notes that a general homogenization of landscapes and agricultural varieties can make rural populations vulnerable to future changes, if genetic traits kept over thousands of years are allowed to disappear. In particular, the loss of genetic diversity in agricultural systems is of particular concern as rural communities face ever-greater challenges in adapting to future climate conditions. In drylands, where production is often operating at the limit of heat and drought tolerances, this challenge is particularly stark. Genetic resources are critically important for the development of farming systems that capture more carbon and emit lower quantities of greenhouse gases, and for underpinning the breeding of new varieties. A breed or variety of little significance now may prove to be very valuable in the future. If it is allowed to become extinct, options for future survival and adaptation are being closed down forever.

### Benefits of genetic diversity in agriculture

The Conference of the Parties to the Convention on Biological Diversity at its tenth meeting in 2010, in its Decision X/34 on Agricultural biodiversity, stresses the importance of agricultural biodiversity for food security and nutrition, especially in the face of climate change and limited natural resources as recognized by the Rome Declaration of the 2009 World Summit on Food Security. It also welcomes, and notes the importance of, the joint work plan between the secretariats of the Convention on Biological Diversity and the Food and Agriculture Organization of the United Nations and its Commission on Genetic Resources for Food and Agriculture. It is noted here that the Food and Agriculture Organization of the UN has been working on the issue of agricultural biodiversity since 1960.

According to the Commission on Genetic Resources for Food and Agriculture, it is estimated that nowadays only 30 crops provide 95 percent of human food energy needs and just four of them – rice, wheat, maize and potatoes – provide more than 60 percent. Given the significance of a relatively small number of crops for global food security, it is of pivotal importance to conserve the diversity within these major crops. While the number of plant species that supply most of the world's energy and protein is relatively small, the diversity within such species is often immense. For example, the number of distinct varieties of the rice species Oryza sativa, is estimated at more than 100,000. Farm communities in the Andes cultivate more than 175 locally named potato varieties. It is this diversity within species that allows for the cultivation of crops across different regions and in different situations such as weather and soil conditions. Plant genetic diversity may also provide valuable traits needed for meeting challenges of the future, such as adapting our crops to changing climatic conditions or outbreaks of disease. Wild botanical relatives of our food crops – often found on the periphery of cultivated lands – may contain genes that allow them to survive under stressful conditions. These genes can add important traits to their cultivated relatives, such as robustness or frost resistance.

According to FAO and the Platform on Agrobiodiversity Research (2010), crop genetic diversity has a critical role to play in increasing and sustaining production levels and nutritional diversity throughout the full range of different agro-ecological conditions.

### Genetic diversity and ecosystem services

As Rao and Hodgkin (2002) point out, the general trend of the past decades has been the release and cultivation of improved cultivars of many major and minor crop species. These cultivars tended to be uniform. They are usually derived from a limited number of elite lines, which are often used in the production of many cultivars, resulting in an increasingly narrow genetic base for the crop. This, together with large-scale cultivation of such genetically uniform cultivars, has increased the genetic vulnerability of many major agricultural crop species, often with disastrous consequences. According to Altieri (1999), in the US, 60-70 per cent of the total bean area is planted with 2-3 bean varieties, 72 per cent of the potato area with four varieties and 53 per cent of the cotton area with three varieties (from the National Academy of Sciences, 1972). Researchers have repeatedly warned about the extreme vulnerability associated with this genetic uniformity.

It should be noted that the benefits from crop genetic diversity to ecosystem services are quite considerable. The conservation and use of plant genetic resources for food and agriculture has been comprehensively reviewed by FAO (1997) in the *First Report on the State of the Worl'd Plant Genetic Resources for Food and Agriculture*. As Altieri (1999) quotes from Brush (1982), genetic diversity confers at least partial resistance to diseases that are specific to particular strains of crops and allows farmers to exploit different soil types and micro-climates for a variety of nutritional and other uses.

However, few studies have addressed in detail the relationship between genetic diversity and provision of ecosystem services in agro-ecosystems. Hajjar et al. (2008) have synthesized the state of knowledge on the utility of crop genetic diversity in maintaining ecosystem services. They argue that the contribution of biological diversity to ecosystem functioning in agricultural production systems is variable, and can be substantial, as it occurs at the genetic, as well as species, level in arable systems. In particular, increasing crop genetic diversity has been shown to be useful in pest and disease management, and has the potential to enhance pollination services and soil processes in specific situations.

In particular, according to Hajjar et al. (2008), diversity, in the form of crop genetic diversity, polycultures, and landscape heterogeneity, each at various temporal scales, has been effectively used to control the spread of and damage caused by pests and diseases in agro-ecosystems. Mechanisms of how diversity can be employed in a field or landscape for pest and disease control are well studied. Soil organisms perform a number of vital functions that regulate the soil ecosystem, including decomposition of litter and cycling of nutrients; converting atmospheric nitrogen to an organic form, and reconverting this to gaseous nitrogen; and altering soil structure (Altieri, 1999).

By contributing to the long-term stability of agro-ecosystems and helping to provide continuous biomass cover, crop genetic diversity also aids the ecosystem to sequester carbon, and helps to prevent soil erosion (Hajjar et al., 2008). In particular, it is the practices that increase species and genetic diversity, at various time scales, and help increase productivity year round, that can indirectly increase the ecosystem's ability to sequester carbon. This includes enhancing soil fertility with practices such as multiple cropping and agroforestry, enhancing crop rotation complexity, adding cover crops year-round, using improved crops or varieties, and planting deep-rooted crops or varieties (Hajjar et al., 2008). FAO and the Platform on Agrobiodiversity Research (2010) also note that genetic diversity contributes both to pest control and to farming practices following ecosystem-based approaches designed to improve sustainability of production systems. By using species or varietal mixtures for pest and disease management and enhanced pollination services, as well as for ensuring the agro-ecosystem against abiotic stresses, one can also increase productivity and long-term stability of the system (Hajjar et al., 2008).

According to the Millennium Ecosystem Assessment (2005, Chapter 26, Cultivated Systems), both theory and observation suggest that genetic heterogeneity provides greater disease suppression when used over large areas. Some studies, including those of wheat mosaic virus (Hariri et al., 2001), fungal pathogens of sorghum (Ngugi et al., 2002), and rice blast (Zhu et al., 2000), have shown that mixed planting of resistant varieties with other varieties can reduce the disease incidence across the whole crop, while possibly extending the functional ‘‘lifespan’’ of the resistant genotypes. However, evolutionary interactions among crops and their pathogens mean that improvement in crop resistance to a pathogen is, in most cases, likely to be transitory. Thus, maintaining stocks of genetic diversity for plant breeding is critically important.

Figure 10, taken from Hajjar et al. (2008), presents the potential benefits of crop genetic diversity in directly (through increased number of functional traits and increased facilitative interactions) and indirectly (through ensured continuous biomass) enhancing agro-ecosystem functioning and provision of services. (Numbers in the figure refer to numbered sections in the text of Hajjar et al., 2008; text within the dotted boxes is provided to clarify the aspects of direct and indirect effects considered in the figure and the original paper.)

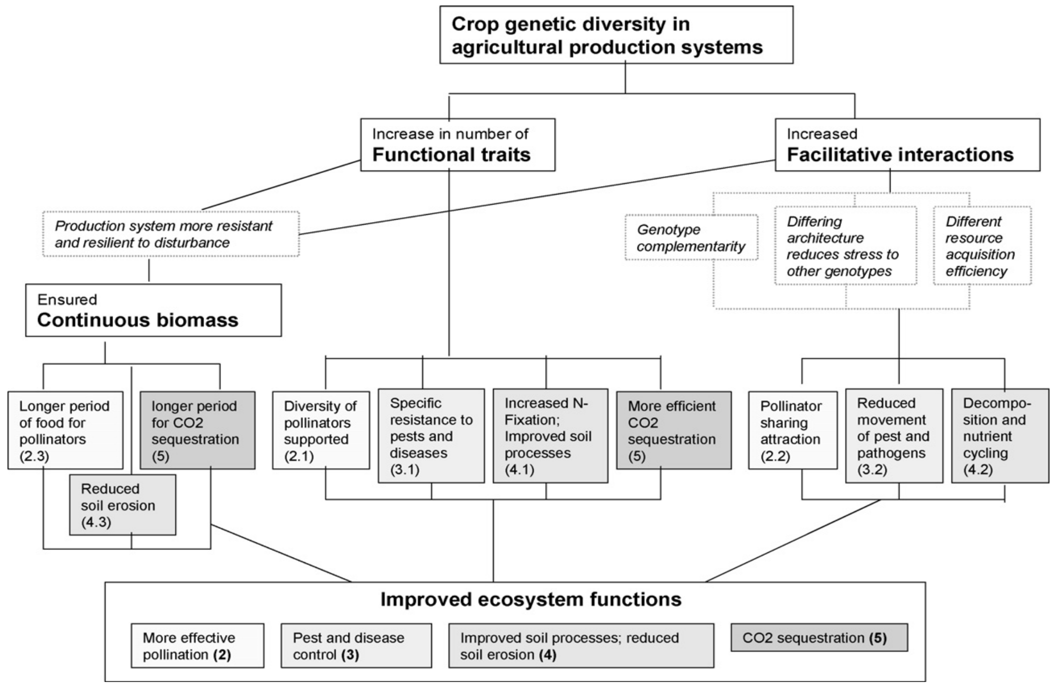



**Figure 10.** Potential benefits of crop genetic diversity enhancing agro-ecosystem functioning and provision of services
Source: Hajjar et al., 2008

Plant genetic resources are the biological basis of food security and, directly or indirectly, support the livelihoods of every person on Earth. Plant genetic resources for food and agriculture (PGRFA) consist of diversity of seeds and planting material of traditional varieties and modern cultivars, crop wild relatives and other wild plant species. These resources are used as food, feed for domestic animals, fiber, clothing, shelter and energy. The conservation and sustainable use of PGRFA is necessary to ensure crop production and meet growing environmental challenges and climate change. The erosion of these resources poses a severe threat to the world's food security in the long term. In this respect, Altieri and Merrick (1987) stress the social and cultural importance of crop gene diversity. Socio-cultural issues make it impossible to view the resources merely as a set of genes that can simply be conserved by sticking them into a gene bank. If isolated from the folk science and traditional uses of the cultures that have nurtured them, they lose part of their value or cultural-historical meaning (Altieri and Merrick, 1987). More research is required in this field, together with research on the implications on nutrition. As Johns and Eyzagirre (2006) point out, research on the properties of neglected and underutilized species and local varieties deserves higher priority; traditional systems once lost are hard to recreate, whereas timely documentation, compilation and dissemination of eroding knowledge of biodiversity and the use of food culture for promoting positive behaviors are imperative.

### Conservation of genetic diversity: The role of seed banks

Gepts (2006) notes that two main complementary methods have been developed to conserve crop genetic diversity. Ex situ (off-site) conservation seeks to maintain genetic resources off site, i.e., in gene banks. The second general category of conservation methods is in situ (on-site) conservation that can take place in farmers' fields for domesticated materials or in natural environments for wild relatives of crop plants or wild species.

Significant progress has been made in ex situ conservation of crops, i.e. the collection of seeds from different genetic varieties for cataloguing and storage for possible future use. Gene banks are an important way to conserve genetic resources, since they provide safe storage to ensure that the varieties and landraces of crops that underpin our food supply are secure and that they are easily available for use by farmers, plant breeders and researchers.

In 1970, there were less than 10 gene banks (Gepts, 2006). Currently, according to FAO estimates, there are approximately 1,500 gene banks maintaining 5.5 million samples. According to Global Biodiversity Outlook 3 (Secretariat for the Convention of Biological Diversity, 2010), for some 200 to 300 crops, it is estimated that over 70 per cent of genetic diversity is already conserved in gene banks, meeting the target set under the Global Strategy for Plant Conservation. The UN Food and Agriculture Organization has also recognized the leading role played by plant breeders, as well as the curators of ex situ collections, in conservation and sustainable use of genetic resources.

Seed banks play an important role in conserving the diversity of plant species and crop varieties for future generations. Among the most ambitious programs for ex situ conservation are the Millennium Seed Bank Partnership, initiated by the Royal Botanic Gardens Kew and its partners worldwide, which now includes nearly 2 billion seeds from 30,000 wild plant species, mainly from drylands; and the complementary Svalbard Global Seed Vault, which has been constructed in Norway, close to the Arctic Circle, to provide the ultimate safety net against accidental loss of agricultural diversity in traditional gene banks. The vault has the capacity to conserve 4.5 million crop seed samples (Global Biodiversity Outlook 3).

Climate change is likely to place new pressures on conservation of genetic diversity for food and agriculture. Genetic material in gene banks will play an increasingly important role for adapting agriculture to climate change, including for screening for different characters (CGR, 2011).

**The case of Greece**

According to the second Greek report to FAO concerning the state on plant genetic resources for food and agriculture (Stavropoulos et al., 2006), genetic diversity in agriculture in Greece is analogous to its rich natural environment and its long agricultural history. In particular, the combination of a favorable natural environment and the agricultural practices of self-sufficiency, in the beginning of the 20th century, have led to the maintenance of a large number of landraces well adapted to the local conditions. The report (Stavropoulos et al., 2006) states that the category includes both species originated or diversified in Greece (leguminous crops such as Cicer, Lens, Vicia, Pisum and Lupinus, vegetables such as Brassica, Lactuca, Cichorium, Beta, trees such as Olea, Ficus, etc. and grapevine) and species introduced in Greece centuries ago which were afterwards evolved and adapted to the local conditions (many fruitplants such as Malus, Pirus, Prunus etc., cereals such as Triticum, Hordeum, Secale, etc., and vegetables such as Phaseolus, Lycopersicon, Solanum, Capsicum, etc.). However modernization of the agricultural production and trades led to the dramatic depletion of PGR that was not appreciated until the end of the1970s.

Although the collection is particularly rich in germ plasm of Cereals, Tobacco, Cotton, Pulses, Forages, Grapevine and Prunus accessions, only a limited part of the broad spectrum of the wild relatives grown in Greece has been collected and conserved at the GGB. Moreover, the limited increase in the number of accessions over the last decade, according to the authors of the second national report (Stavropoulos et al., 2006), reflects the genetic erosion and the irreversible loss of the traditional landraces in Greece and the difficulty in finding and saving such germ plasm in our days. The material stored in the GGB is potentially unique and useful, for breeders, in order to keep stable or to improve the yielding ability, stability and plant health of cultivated plants, or to exploit new environments, including as an option of adaptation to climate change. Moreover, this material is also extremely valuable, since in Greece there is increased awareness regarding the conservation of genetic diversity in agriculture, in the framework of a broader interest in biodiversity conservation. In particular, there is a growing interest now in Greece for using local landraces in organic farming programs by individual farmers or ecologically sensitive groups, since local germ plasm is best suited for low input farming, or for their fine quality and suitability to local traditional preferences and tastes (Stavropoulos et al., 2006). This provides an opportunity for measures at the national and EU level to implement certain aspects of Farmers' Rights, particularly for the conservation, participatory breeding (especially for low-input agriculture) and participation of farmers in relevant decisions.

### Challenges and prospects for Gene Banks

There are many challenges facing gene banks; apart from collection, proper documentation, evaluation and maintenance are required (Wright, 1997). According to the Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture (FAO, 2010), gene bank collections are still at risk. In particular, according to the aforementioned report, the following risks are mentioned: although many of the accessions held in gene banks are duplicates, not all collections are systematically duplicated, and those that are not are at risk of losing unique accessions due to technical failures, disease or any of a host of possible calamities. Coverage of crops is also uneven. For some, such as wheat and rice, much of the genetic diversity is already represented in collections, but for many others there are still large gaps. Indeed, many useful plant species are found only in the wild or as landraces in farmers' fields. Much more needs to be done to rationalize gene bank collections. There is great concern regarding the lack of regeneration of aging stocks of accessions and the paucity of documentation, including characterization and evaluation data in many gene banks. Many countries report shortages of funding and skilled staff to operate their gene banks. Lack of data standardization means that sharing of data with other users is difficult, if not impossible. The Global Crop Diversity Trust is funding regeneration and documentation efforts, but greater efforts are needed to build a truly rational global system of ex situ collections. This will require policy vision, trust and technical cooperation among all members engaged in this cause.

With regard to the Greek Gene Bank, the major challenges are continuation of collection, regeneration of aging stocks, documentation, evaluation and maintenance of facilities.

Research and urgent action are required to meet the ecological and social challenges ahead of us. Today, it has become clear that the best strategy combines ex situ conservation with on-the-ground (in situ) conservation by farmers in their agro-ecosystems and of crop wild relatives in, for example, areas protected for their environmental value. As Esquinas-Alcazar (2005) has underlined, we should ensure that the benefits derived from plant genetic resources reach all those who need them, and thus, public-sector research is needed in areas in which the private sector does not invest. Most commercial crop varieties are not adapted to the needs of poorer farmers who have limited or no access to irrigation, fertilizers and pesticides. A new environmentally friendly, socially acceptable and ethically sound agricultural model is needed to meet their needs. This could be achieved by using publicly supported programs to breed crops that are able to withstand adverse conditions, including drought, high salinity and poor soil fertility and structure, and that provide resistance to local pests and diseases. Such programs are likely to build on farmers' existing varieties, which often contain these traits. There are encouraging examples of this kind of research, which needs to be supported. The entry into force of the International Treaty for PGRFA provides hope for fighting hunger and malnutrition, including at the local level. Its provisions on sustainable use, farmers' rights and benefit-sharing allow for cooperation between farmers and breeders in genetic improvement at the level of traditional farmers' varieties, rather than just seeking uniform "universal genotypes".

## 3. VALUES GENERATED BY THE GREEK GENE BANK: VALUATION METHODOLOGY

### Introduction

Within the "Total Value" framework the values generated by a gene bank can be broadly divided into two categories:

(i) Use values associated with the value of genetic resources held by a gene bank in developing new foods or drugs. Using genetic resources, the breeders develop new improved varieties with characteristics such as higher pest and disease resistance, resilience to climate change or increased productivity to enhance food production.

(ii) Non-use values which are related to bequest motives for conserving genetic material for the future.

In a recent survey Smale and Hansen (2010) identify the following values associated with a gene bank:

1. The value of collections of genetic resources associated with use of collection material to improve resistance of crops to disease and help enhance agricultural yields and mitigate the threat of economic problems in production of major food staples (e.g. developing wheat varieties with resistance to the Russian wheat aphid).
2. The value of plant genetic resources used to improve crop productivity.
3. The value of plant genetic resource accessions as a means to promote research on an international as well as a national level in order to support development of world agriculture.
4. The value of germ plasm flows from international repositories such as the centers of the Consultative Group on International Agricultural Research (CGIAR) and its International Agricultural Research Centers to benefit development of national research efforts.
5. The value of information. This is the value of information relating to research using genetic resources to produce new goods such as new crop varieties or drugs. The information value relating to the collection of genetic resources of a gene bank has public good characteristics.
6. Direct and indirect value to farmers associated with direct distribution of genetic resource materials such as seeds to farmers.
7. Use of the gene bank materials collection to benefit vulnerable and subsistence-oriented agricultural communities as a means to combat poverty.

In terms of non-use values the **existence value** associated with the gene bank should also be noted. This is the general existence value stemming from preserving the varieties in all accessions of the gene bank for future generations.

In order to provide quantitative approximations of the value of the gene bank, the present study will focus on two particular types of values associated with the accessions[3] of a gene bank: insurance value and productivity value.

### Insurance value

Crop genes can offer increased opportunity for plant breeding to develop improved varieties that can insure food harvest against risks from natural phenomena. Extreme events such as prolonged drought or disease can limit agricultural production, preventing sufficient supply of food in the market or limiting people's capacity to buy food. Changes in market supply can cause prices to shift adding unpredictability to the costs of food facing the consumers. Evidence moreover from the 2006-08 surge in food prices indicates that volatility in food prices even if only short term can have large long-term consequences on the wellbeing of vulnerable groups.

Valuation studies undertaken indicate that crop diversity can be an important factor, in economic terms, in ensuring food security. Crop wild relatives for instance are known for their high potential to provide disease resistance because they have closely existed with pathogens with which they have reached fine biological balances. Wild relatives are estimated to have contributed approximately US$ 340 million per year, through yield and disease resistance, during the period 1976-1980, to the farm economy of the United States (Shand, 1997).

Moreover by narrowing the number of plants, modernization and industrialization of agriculture has increased vulnerability of food production to potential outbreaks of plant disease. Put in very simple terms, modernization of agriculture over the past century has increase agricultural outputs while decreasing the number of plants farmed. Only one tenth of biological diversity has been combined to produce major crops farmed globally today, with a small number of disease resistance traits incorporated in these crops. A recent example indicating the importance of having a broad genetic base to breed plants with disease resistant characteristics is the case of maize in the US. An outbreak of a disease known as Southern corn leaf blight (Helmithosporium maydis) caused severe losses in the maize crop in the US in the

[3] An accession is a sample of planting material stored in an ex situ collection of genetic resources. Accessions may or may not be unique and are not necessarily homogeneous.

1970s. However precautionary breeding of disease resistant varieties by American farmers who used material from a wide gene pool helped control the impacts of the devastating epidemic within as little as 2-3 years following the outbreak of the disease.

### Productivity value

Conservation of crop diversity by gene banks can play a key role in helping breed improved agricultural varieties to bridge the yield gap and to meet future global needs for food. Food production has increased dramatically over the past century. Breeding of improved crop varieties with higher yields played a central role in increasing outputs, which also rose as a result of the use of fertilizers, herbicides, pesticides, and mechanization. As much as 20-40 per cent of increased yields between 1945 and 1990 are estimated to be attributed to plant breeding (Pimentel et al., 1997).

Wheat improvement in Greece over the period 1930-1970 successfully shows the potential of productivity gains associated with having a large genetic pool. By effectively developing new varieties with improved traits including resistance to frost and disease, the National Cereal Institute helped achieve increases in wheat production of up to 300 per cent between 1930 and 1967.

In the future, an increase in agricultural yields will continue to be necessary. Just satisfying the expected food and feed demand will require a substantial increase of global food production of 70 percent by 2050, according to projections made by the Food and Agriculture Organization. Additionally new crop varieties will need to help decrease pressure on the environment by being less demanding on water and soil nutrients while being adapted to a changing climate.

Although other types of values could be quantitatively important, we will not attempt to estimate them empirically in this study because of the considerable uncertainties involved and the lack of appropriate data. In any case we believe that insurance and productivity are two major sources of values generated by gene banks, which can at least be approximated in a meaningful way from existing data.[4] If the GGB can be justified economically by accounting for the insurance and the productivity value only, it is clear that the other sources of value can further support it.

Regarding the measurement of insurance and the productivity values, we develop first a conceptual framework which is based on the expected value of benefits which

[4] For example, Zohrabian et al. (2003) is the only attempt to measure the marginal value of an accession. Zohrabian et al. (2003) found that the expected marginal benefit from exploring an additional unimproved gene bank accession in breeding resistant varieties of soybean more than covered the costs of acquiring and conserving it.

are generated when a gene bank accession is used in the future to provide a novel variety after a destructive event, or to enhance the productivity of an existing variety.

### Estimating insurance values

We consider the case where the occurrence of a set of undesirable events in the future will damage the value of production of an existing commercial variety. These events could be for example pest outbreaks, diseases, reduced precipitation, heat waves, extreme weather events, etc. The assumption is that a specific accession of the gene bank can be used to develop substitutes for the affected variety and at least partially recover the lost production value. We will call the event or combination of events that will cause the production loss of an existing variety and that will give rise to the need to employ resources of the gene bank the *triggering event.*

*Modeling the arrival of the triggering event.* The usual approach for modeling the arrival of stochastic events is the use of the Poisson process. We start by assuming that the arrival of triggering events follows a homogeneous Poisson process $N(t)$ with rate (or intensity) $\lambda$. The arrival of the undesired events can be defined using the Poisson process as:

$$\Pr\left[N(t+\tau)-N(t)=k\right]=p(k)=\frac{e^{-\lambda\tau}(\lambda\tau)^k}{k!},\ k=0,1,... \tag{1}$$

where $(N(t+\tau)-N(t))=k$ is the number of events in the time interval $(t,t+\tau]$. Thus the above expression provides the probability that between time *t* and time $t+\tau$ the undesirable events will occur *k* times, where λ is the expected number of occurrences of the events between time *t* and time $t+\tau$. For example if we are at the present time $t=0$, and we expect in the next decade 15 undesirable events and that for the reduction in productivity of a given variety 20 events are required, then $\lambda=15, k=20$ and the probability of having the twenty events, regarding the decade as the unit of time, is 4.18 per cent.

In this type of modeling there are two issues that should be further addressed.

The first is that given the uncertainty and the complexity about the nature and the timing of the arrival of the events that will eventually trigger the use of the gene bank we consider, in order to make practical approximations possible, only one triggering stochastic event. This event could be regarded as a “threshold”, which occurs after the occurrences of other related events (e.g. increase in the number of hot days in the summer, reduced precipitation) and leads to severe damages in the commercial value of the variety's production. To put it differently, the triggering event could be the manifestation of a composition of different stochastic shocks associated with climate change or other external drivers. This threshold event will trigger the use of the gene bank for the provision of substitute or improved varieties. Avoiding losses associated with a sudden shock in the supply of food represents a reflection of the value of insurance offered by the gene bank. The recovery of the expected commercial value obtained through the use of the gene bank will reflect the insurance value of the gene bank for this specific variety.

The second issue is that since climate change is expected to increase the number of undesirable events for agriculture, a non-homogeneous Poisson process where the rate $\lambda$ is an increasing function of time could be a better way of modeling.

Thus we model the arrival of the triggering event that will stimulate research to engineer new plants using the collection of the gene bank, by the cumulative distribution function of a gamma distribution defined as:

$$g\left(t;\alpha,\beta\right)=\beta^{\alpha}\frac{1}{\Gamma\left(\alpha\right)}t^{\alpha-1}\mathrm{e}^{-\beta t},t\geq 0,\alpha,\beta>0,\Gamma\left(\alpha\right)=\left(a-1\right)!$$

where $\alpha$ is the shape parameter and $\beta$ is the rate parameter.

The cumulative distribution function is defined as

$$F\left(t;\alpha,\beta\right)=\int_0^t g\left(\tau;\alpha,\beta\right)d\tau=\frac{\gamma\left(\alpha,\beta t\right)}{\Gamma\left(\alpha\right)}$$

where $\gamma\left(\alpha,\beta t\right)$ is the lower incomplete gamma function, $\gamma\left(\alpha,\beta t\right)=\int_0^{\beta t}u^{\alpha-1}\mathrm{e}^{-u}\,du$.

Let $m\left(t\right)=F\left(t;\alpha,\beta\right)$. Since $0\leq m\left(t\right)\leq 1$ for all $t$, if there exists an $m\left(t_0\right)\approx 1$ we will interpret $t_0$ as the time at which the expected triggering event will arrive.

The triggering event is however stochastic. We model the probability of arrival of this single composite event by a non-homogeneous Poisson process.

In general a non-homogeneous Poisson process provides the probability that $N\left(t\right)$ events will arrive at time $t$, and is defined as:

$$\Pr\left(N\left(t\right)=k\right)=p\left(t,k\right)=\frac{m\left(t\right)^{k}\mathrm{e}^{-m\left(t\right)}}{k!} \qquad (2)$$

where $N(t)=k$ is the number of events by time *t* and $m(t)=\int_0^t \lambda(u)\,du$ is the mean occurrences up to time *t,* with $\lambda(u)$ being the number of expected occurrences at time *u*. The number of events in the interval $(t,t+\tau]$ which is $N(t+\tau)-N(t)$ is a Poisson random variable with rate $m(t+\tau)-m(t)$.

In our case, we are considering a single composite triggering event. Therefore $k=1$ and

$$\Pr\left(N(t)=1\right)=p(t,1)=m(t)\mathrm{e}^{-m(t)} \tag{3}$$

is the probability that the triggering event will arrive at time *t.*

It should be noted that since $0\le m(t)=\int_0^t \lambda(u)\,du\le 1$, $m(t)$ can be interpreted as the fraction of the events that constitute the composite triggering event which have occurred up to time *t*. The triggering event will emerge at $t_0$ if $m(t_0)\to 1$. Figure 11 presents the function $m(t)=F(t;10,2)$.[5]

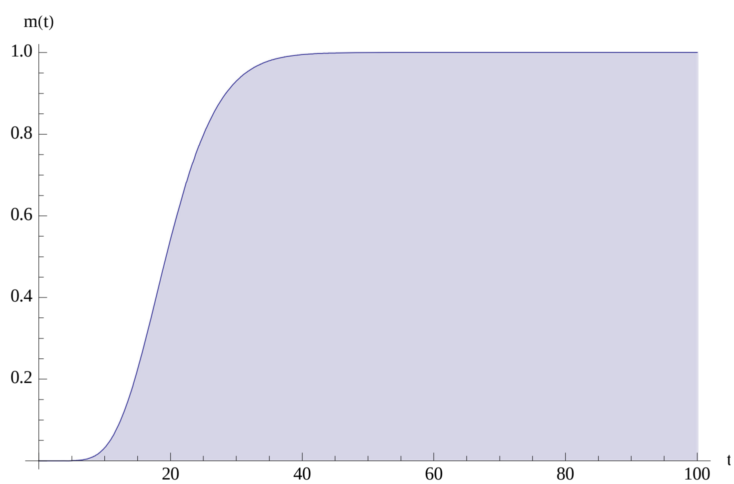



**Figure 11.** The expected arrival of the triggering event

The value $m(20)=0.542070$ can be interpreted as indicating that 20 time periods from now it is expected that 54.21 per cent of the events leading to the triggering

[5] All calculations and simulations were conducted using the software Wolfram Mathematica 8.

event will occur. The value $m(45)=99.89$ implies that it is expected that the triggering event will occur 45 time periods from now.

The arrival probability of the triggering event at any point of time $t \in [0,T]$ is given by $p(t,1)=m(t)e^{-m(t)}$ and it is shown in Figure 12.

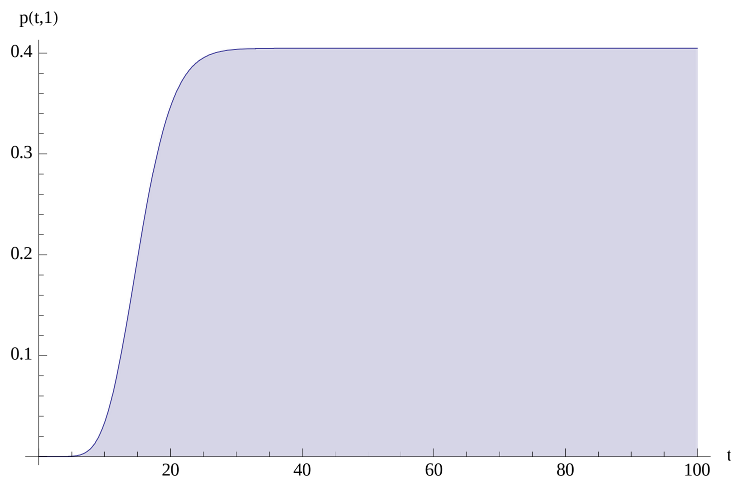



**Figure 12.** Arrival probabilities for the triggering event

As Figure 12 shows, the probability of having the triggering event early is low. For example, *p*(10,1)=0.0339, implying that the probability of having the triggering event 10 years from now is 3.4 per cent. On the other hand , *p*(45,1)=0.4046, suggesting that the probability of having the triggering event 45 years from now is 40.46 per cent and remains approximately constant after that. It remains constant because we have assumed that we expect the arrival the destructive event approximately 45 years from now.

***Insurance Value Estimation***

Assume that the flow of the value of agricultural production lost due to the triggering event is $R_{t,t+\tau}, t, \tau = 0,1,2....$ where *t* is the time when the event occurs. Under the simplifying assumption that the triggering event is totally destructive, $R_{t,t+\tau}$ is the flow of the commercial value of the agricultural production of the given variety. Thus $R_{4,9}$ is the loss five periods after the event which took place at $t=4$. The probability of the triggering event occurring at time *t* is given by the non-homogeneous Poisson process $p(t,1)$ defined in (3).

Once the event occurred, the recovery would not be instantaneous because there is a time lag between the triggering event and the development by the gene bank of substitute varieties that can successfully replace commercial production. The factors and the costs determining the capacity of the gene bank to help the recovery of agricultural production are presented below. For the purposes of the conceptual model we will assume that there is a delay period of length $d$ for the breeding of a novel variety, and after that there is another delay of length $d'$ until the new variety becomes fully operational as a substitute for the damaged variety.

Let $V_t = \sum_{\tau=0}^{T} \frac{R_{t,t+\tau}}{(1+r)^{t+\tau}}$ be the present value now of losing at time *t* the commercial value of a variety due to the arrival of the triggering event at time *t.* These losses correspond to the annual losses of agricultural production of the commercial variety from the time of the triggering event, until some sufficiently large time *T.* This time denotes the time horizon over which the affected variety would have been productive, if the triggering event had not emerged.

Assume: (i) a delay $d+d'$ until the novel variety becomes fully commercially operational, (ii) $C_h$ development costs until the novel variety becomes fully operational, $h=1,...,d+d'$, (iii) linear recovery of the commercial value during $d'$, and (iv) a constant annual flow *R* for the commercial value of the agricultural production, in order to simplify notation without influencing robustness of the exercise.

Then the present value of the recovered commercial production if the triggering event occurs at time *t* will be:

$$RV_t = \frac{\theta}{(1+i)^{t+d}} \left[ \frac{1}{d'}R + \frac{1}{(1+i)}\frac{2}{d'}R + ... + \frac{1}{(1+i)^{d'-1}}\frac{d'-1}{d'}R + \sum_{\tau=0}^{T-d'} \frac{R}{(1+i)^{\tau+d'-1}} \right] - \sum_{h=0}^{d+d'} \frac{C_h}{(1+i)^{t+h}} \quad (4)$$

where $0 < \theta \leq 1$ is a recovery coefficient. If $\theta = 1$, the new variety provides full recovery for the damaged variety. The recovery coefficient can also be interpreted as the proportion of the total commercial value that is affected by the triggering event. For example, $\theta = 0.5$ means that only 50 per cent of the commercial value is affected by the triggering event. Of course the recovery coefficient can be interpreted as a combination of the proportion of recovery and the proportion of affected value.

To transform this recovered value into an insurance value, the present values should be weighted by the probability that the triggering event will occur at time *t.*

The sequence

$$p(0,1)RV_0, p(1,1)RV_1, p(2,1)RV_2, ..., p(\tau,1)RV_\tau, ... \quad (5)$$

denotes the expected present value of the accession in terms of the sum of values of agricultural output recovered with use of the gene bank resources after adverse events in the supply of food at different points in time.

Therefore each specific term of the sequence indicates, in present value terms, the insurance value of the gene bank with respect to the specific variety at each point of time. Thus $p(2,1)RV_2$ is the insurance value of the gene bank, at $t=2$. The insurance value of the gene bank increases with the probability of occurrence $p(t,1)$.

Let us denote each element of the collection of the expected present values (5) by

$$\{EV(0), EV(1), ..., EV(\tau), ...\}. \quad (6)$$

We will define as the insurance value (*IV*) of the gene bank with respect to the specific variety, the maximum element of (6) or:

$$IV = \max\{EV(0), EV(1), ..., EV(\tau), ...\}. \quad (7)$$

The value of the gene bank for the specific variety is therefore the maximum expected value of the commercial agricultural production which is expected to be recovered by using the accession of the gene bank, if a destructive stochastic event occurs in the future.

**Application: Insurance value for wheat**

We provide a valuation example by using data on wheat production in Greece.[6] We make the following assumptions for this example:

- Within the next 100 years the effects of climate change will produce an event that will have destructive effects on wheat production in Greece. The event will trigger the development of new varieties from the genetic stock held by the GGB. This triggering event is expected to occur after 45 years, with mean arrival shown in Figure 11, and arrival probabilities for the next 100 years shown in Figure 12.
- The future annual flow of the commercial wheat production will be 338.51 million euros, which is the average yearly production for the period 1995-2006. We make the "small country assumption" and assume that wheat prices are exogenous and

[6] Analytical valuations for seven varieties with genes held by the GGB are presented in the next chapter.

not affected by the actions of the GGB.[7] Details regarding the agricultural production are provided below.

- It will take ten years after the triggering event to develop a novel substitute variety and another five years to reach the full commercial production value of 270 million euros. We assume a recovery coefficient of $\theta = 0.5$ and, in the absence of any relevant information, we do not take into account development costs.
- We use a real discount rate of 5 per cent and a time horizon of 50 years to calculate the present value of wheat production so that *T*=50.

Figure 13 shows the potential loss in value of wheat production if the triggering destructive event occurs within the next 100 years.

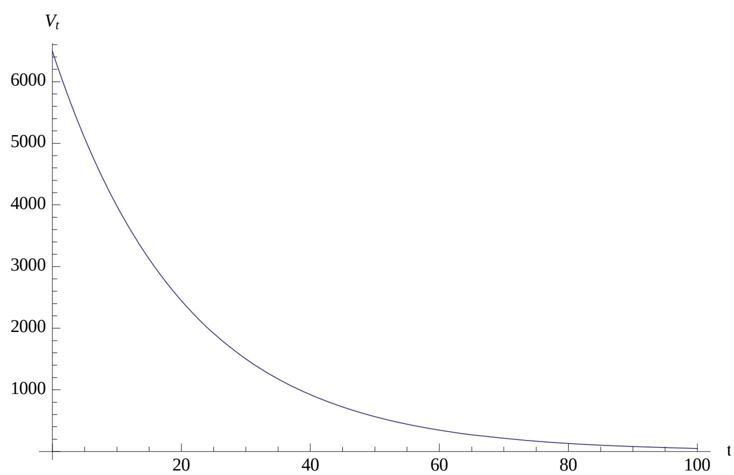



**Figure 13.** Potential loss of wheat production

This figure should be interpreted in the following way. $V_{10} = 3983.56$ means that the present value now of losing after t=10 years the wheat production for the next 50 years is 3983.56 million euros.

The losses potentially recovered due to the GGB, which are calculated using (4) and assuming a recovery coefficient of $\theta = 0.5$, are shown in Figure 14.

[7] It should be noted however that a destructive event that will affect wheat in Greece will probably have a wider effect on the Mediterranean wheat production. This will probably reduce demand and increase future prices. Given the uncertainties and the associated difficulties in modeling these effects, we do not consider their effects which, if they actually emerge, will increase the insurance value of the GGB even further.

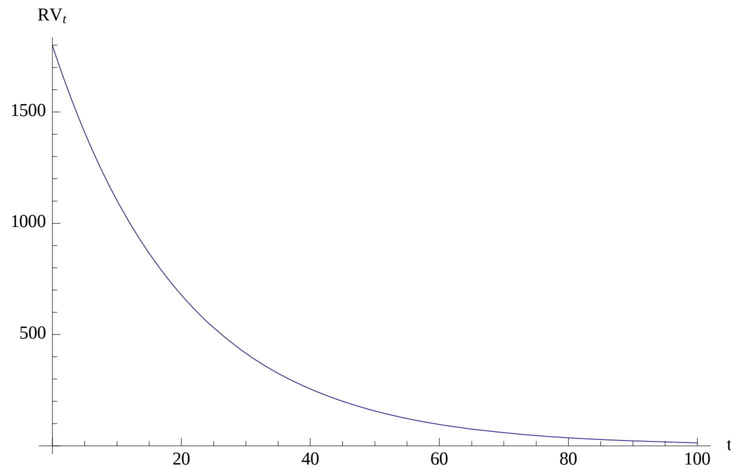



**Figure 14.** Potential recovered losses

Figure 14 should be interpreted in the following way. $RV_{10} = 1103.4$ means that the expected present value now of the recovered wheat production, after a triggering destructive event occurs 10 years from now is 1103.4 million euros. The ratio of the recovered present value to the lost present value is approximately 28 per cent.

The collection of the expected values defined by (6) is shown in Figure 15.

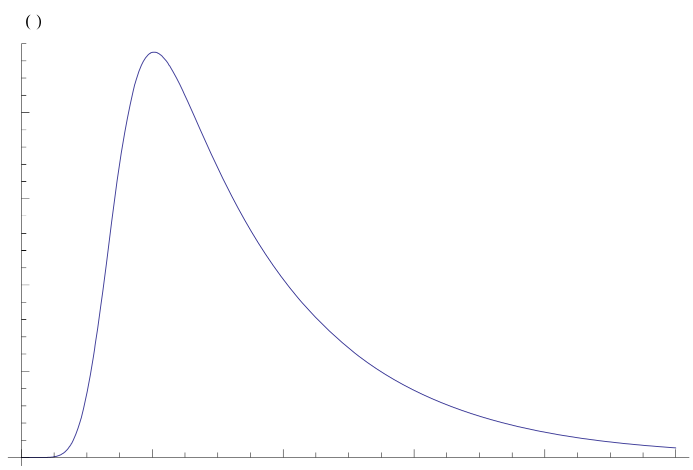



**Figure 15.** Expected recovery values

Figure 15 should be interpreted in the following way. $EV(10) = 37.42$ means that the expected present value of the recovered wheat production ten years from now is

37.42 million euro. Note that for the near future the expected recovery value is almost zero, because the probability of the arrival of the triggering event is very small.

The maximum expected recovered value is 235 million euros, which will be an approximation of the insurance value provided by the GGB with respect to wheat production.

It should be noted that this value should be regarded as an upper bound for the insurance value, given the assumptions above, because it has been calculated without deducting the cost of developing the substitute wheat variety. This upper bound value should be regarded as the maximum cost for keeping the GGB and engaging in processes that will develop new substitute varieties of wheat.

### Productivity values

The productivity value emerges through breeding of new improved crop varieties with beneficial traits from the genetic pool of the bank that increase productivity of yields. In order to value the accession in terms of productivity value, we follow the approach developed by Simpson et al. (1996) for valuing potential discoveries from genetic resources collections in the pharmaceutical industry.[8]

Consider an accession of genetic resources with *n* contents, and assume that, with the existing technological knowledge, any material of the accession, which is randomly sampled, may increase the productivity of an existing commercial variety or that will yield a new commercial variety after appropriate R&D and product development costs. Let the probability of success when the first variety is sampled be $x(t)$. Each new sampling is treated as a new Bernoulli trial with equal probability of success. Thus if the first trial is not successful, the probability of success in the second trial is $(1-x(t))$, the probability of success of the third trial if the second is unsuccessful is $(1-x(t))^2$, and so on until the whole accession is sampled. When a success occurs the research activity for this collection is completed. We assume that the probability of success at the first trial is dependent on time to indicate that the success probability may increase due to increased knowledge generated during the process of the R&D activity.

[8] See also Rausser and Small (2000) for the use of research leads in bioprospecting.

Let $z(t+\tau)$, $t,\tau = 0,1,2,...$ be the annual flow of benefits realized from a productivity enhancement if the success after *n* trials occurs at time $t = 0,1,...$, and let $\frac{W(t)}{(1+i)^{t+d}}$ be the present value of the annual benefit flow $z(t+\tau)$ in terms of agricultural value from the productivity enhancement or the new commercial variety, when there is a delay of *d* years between the success and the commercial development of the more productive variety. Let also $c_t$ be the present value of the cost associated with R&D and product development costs for the productivity enhancing development.

The productivity value of the accession of *n* varieties at time *t* will be:

$$
\begin{aligned}
&PV_t(n) = x(t)W(t) - c_t + (1-x(t))(x(t)W(t) - c_t) + \\
&(1-x(t))^2 (x(t)W(t) - c_t) + ... + (1-x(t))^{n-1}(pW(t) - c_t) = \\
&= \frac{x(t)W(t) - c_t}{x(t)}\left[1 - (1-x(t))^n\right]
\end{aligned} \tag{8}
$$

We will define as the productivity value *PV* of the collection the maximum of (8) with respect to time *t*, or

$$PV = \text{argmax}_t \; PV_t(n) . \tag{9}$$

**Application: Productivity value for wheat**

We provide a valuation example by using data on wheat production in Greece.

We make the following assumption:

The average productivity in terms of wheat production for the ten-year period 1995-2006 is 0.498 tons/stremmas. We assume that a productivity enhancement from the gene bank that contains 600 wheat accessions could reach a value of 10 per cent considered by current research as a feasible improvement in crop performance (see Reynolds et al., 2011). This productivity increase will have an annual value of 34.73 million euros valued at the average wheat value for the 11 year period.

The probability $x(t)$ that first trial is successful at time *t* is given by an incomplete Beta function calibrated so that the long-run probability of success at the first trial is approximately zero now and increases with time until it reaches a long-run steady state value or 0.000012 which is compatible with calibrations in Simpson et al. (1996). This incomplete Beta function is defined as:

$$B(v,a,b)=\int_0^v u^{a-1}(1-u)^{b-1}\,du\ ,\ v=\frac{t}{1+t}\ a=15, b=1.9 \quad (10)$$

and is shown in Figure 16.

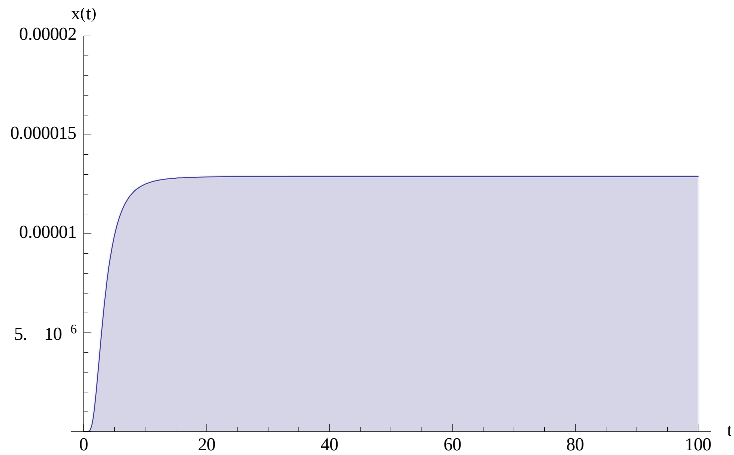



**Figure16**. Probability of success in enhancing productivity

The parameter values used to calculate productivity value defined by (8) are summarized below:

<u>Parameter values</u>

$x(t)$: Incomplete Beta [16,5], $z(t+\tau)=34.73$ million euros per year for 50 years, $n=600,\ i=0.05$.

The productivity value as a function of time is shown in Figure 17. The maximum of this function, which, according to our definition is the productivity value of the wheat accession, is 1.84 million euros.

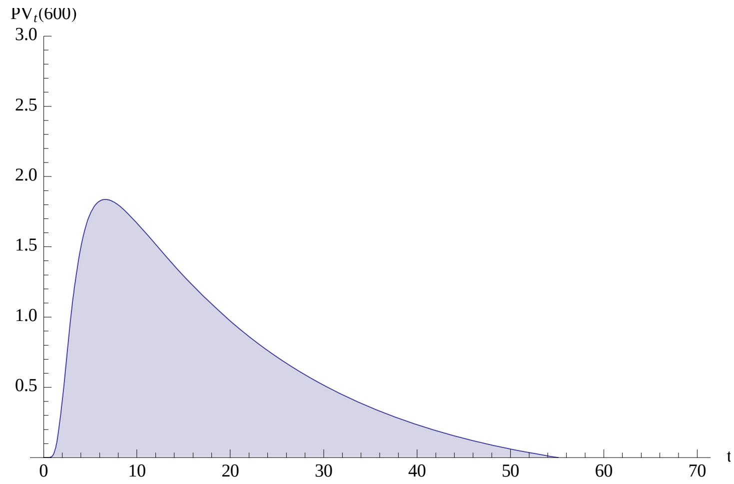



**Figure 17.** Productivity value

Figure 18 shows productivity value as a function of the probability of success at the first trial.

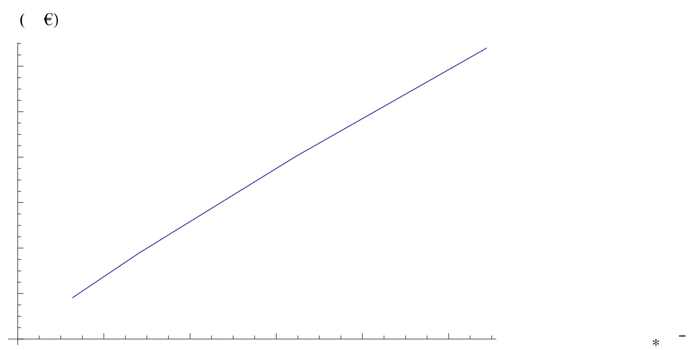



**Figure 18.** Productivity value and probability of success

As expected, the productivity value increases as the probability of success at the first trial increases. More details about the structure of Figure 18 are provided in the next section.

## 4. VALUATION OF THE GREEK GENE BANK

We apply the methodology developed in the previous section to seven crop varieties that constitute crops of interest within the collection of the Greek Gene Bank. The crops selected are wheat, tobacco, pulses, white cabbage, vetches, grapes, and sugar beets.

### Insurance value

To apply the methodology regarding the insurance values stemming from the Greek Gene Bank, we need two types of information: (i) information about the arrival of the triggering event, and (ii) information about the value of the agricultural production affected by the adverse event.

#### *The triggering event*

Food genetic resources are expected to play an important role in helping to develop new crop varieties with climate resistant characteristics to counter adverse impacts of climate change on agriculture. A recent study by the Bank of Greece (2011) about the impact of climate change in Greece estimates the impact on agriculture to be more than 10 per cent losses during 2041-2051 on wheat production in big regions of Greece. Actually wheat is regarded as the most sensitive product to climate change. The same study estimates reductions on grapes at around 10 per cent during 2091-2100 in southern Greece and the islands. The GGB keeps accessions related to wheat and grapes

Similar indications are provided by Skuras and Psaltopoulos (2012) for the Mediterranean area. They state, following Iglesias et al. (2007), that the main risks to agricultural production imposed by climate change in Europe result from changes in the following factors:

1. Water resources and irrigation requirements;
2. Soil fertility, salinity and erosion;
3. Crop growth conditions, crop productivity and in crop distribution;
4. Land use;
5. Optimal conditions for livestock production;
6. Agricultural pests and diseases; and

7. Increased expenditure in emergency and remediation actions.

Regarding agricultural pests and diseases Skuras and Psaltopoulos (2012) indicate that:

*"Climate change and especially higher air temperatures will create conditions suitable for the invasion of weed, pest and diseases adapted to warmer climatic conditions. The speed at which such invasive species will occur depends on the change of climatic change, the dispersal rate of the species and on measures taken to combat non-indigenous species (Anderson et al., 2004). The dispersal rate of pests and diseases are most often so high that their geographical extent is determined by the range of climatic suitability (Baker et al., 2000). The Colorado beetle, the European corn borer, the Mediterranean fruit fly and karnal bunt are examples of pests and diseases, which are expected to have a considerable northward expansion in Europe under climatic warming. Alcamo et al. (2007) review the relevant literature and argue that —increasing temperatures may also increase the risk of livestock diseases by (i) supporting the dispersal of insects, e.g., Culicoides imicola, that are main vectors of several arboviruses, e.g., bluetongue (BT) and African horse sickness (AHS); (ii) enhancing the survival of viruses from one year to the next; (iii) improving conditions for new insect vectors that are now limited by colder temperatures."*

This evidence suggests that climate change is likely to induce a triggering event that may necessitate the use of the gene banks in order to recover, at least partly, lost production. However given the uncertainties involved, it seems that point estimates of the arrival of this event will not be very useful. Thus we decided to build a scenario analysis to evaluate the insurance value for a range of alternative hypotheses at varying points in time and for various probabilities of arrival of the adverse event. In particular we examined nine scenarios with arrival of the event in $Y = \{45, 60, 80\}$ years in the future, and probability of arrival at the specific year $P = \{0.1, 0.2, 0.4\}$. Combining by using $Y \otimes P$ derives the nine scenarios. These scenarios may be regarded as capturing both optimistic expectations (that is, the triggering event will arrive 80 years from now with a probability of 10 per cent) and pessimistic expectations (that is, the triggering event is will arrive 45 years from now with a probability of 40 per cent). Optimistic expectations are associated with low insurance values, while pessimistic expectations are associated with high insurance values.

***The value of affected production***

To approximate the value of potentially lost production due to the triggering event, we use as a base the value of agricultural production of each variety. We consider as reliable data regarding the varieties of interest, time series data on values of production, and cultivated areas between 1990–2006. The data were obtained by the Hellenic Statistical Authority (ELSTAT).[9] A summary of the time series used is presented in Tables 2-8 and a detailed presentation is relegated to the appendix. Reported values are in constant 2005 euros. The names that the GGB uses for the varieties held and the corresponding accessions do not fully correspond to names used by ELSTAT. When there is a difference in names we provide in parentheses the general variety name used by the GGB whose commercial value appears in ELSTAT under a different name. For all practical purposes the ELSTAT name and data correspond to a subset of the accessions of the variety.

**Table 2. Total wheat (soft and hard wheat)**

| Year | Value of production, in million euros | Value per area, in million euros per 1000 stemmas | Production per area, 1000t per 1000 stremmas |
|---|---|---|---|
| 1995 | 535.56 | 0.13 | 0.54 |
| 1996 | 390.01 | 0.09 | 0.49 |
| 1997 | 397.20 | 0.09 | 0.49 |
| 1998 | 351.33 | 0.08 | 0.50 |
| 1999 | 303.79 | 0.07 | 0.48 |
| 2000 | 348.47 | 0.08 | 0.53 |
| 2001 | 376.54 | 0.09 | 0.52 |
| 2002 | 314.89 | 0.08 | 0.49 |
| 2003 | 272.01 | 0.07 | 0.42 |
| 2004 | 303.26 | 0.08 | 0.53 |
| 2005 | 262.34 | 0.07 | 0.52 |
| 2006 | 206.75 | 0.06 | 0.48 |
| Mean value | 338.51 | 0.082 | 0.50 |
| Std. dev. | (80.22) | (0.02) | (0.03) |

[9] http://www.statistics.gr/portal/page/portal/ESYE

**Table 3. Tobacco, all varieties**

| Year | Value of production, in million euros | Value per area, in million euros per 1000 stremmas | Production per area, 1000t per 1000 stremmas |
|---|---|---|---|
| 1995 | 372.82 | 0.54 | 0.21 |
| 1996 | 346.71 | 0.51 | 0.22 |
| 1997 | 328.30 | 0.49 | 0.22 |
| 1998 | 287.01 | 0.43 | 0.22 |
| 1999 | 228.09 | 0.35 | 0.22 |
| 2000 | 194.48 | 0.32 | 0.22 |
| 2001 | 200.08 | 0.32 | 0.23 |
| 2002 | 223.00 | 0.38 | 0.22 |
| 2003 | 189.76 | 0.33 | 0.24 |
| 2004 | 201.06 | 0.36 | 0.24 |
| 2005 | 160.00 | 0.29 | 0.23 |
| 2006 | 372.82 | 0.54 | 0.21 |
| Mean value | 258.68 | 0.41 | 0.23 |
| Std. dev. | (74.74) | (0.09) | (0.01) |

**Table 4. White cabbage (Brassica)**

| Year | Value of production, in million euros | Value per area, in million euros per 1000 stremmas | Production per area, 1000t per 1000 stremmas |
|---|---|---|---|
| 1995 | 60.89 | 0.68 | 2.19 |
| 1996 | 39.88 | 0.44 | 2.12 |
| 1997 | 64.52 | 0.72 | 2.10 |
| 1998 | 54.87 | 0.61 | 2.09 |
| 1999 | 62.88 | 0.70 | 2.10 |
| 2000 | 64.83 | 0.71 | 2.16 |
| 2001 | 69.46 | 0.79 | 2.23 |
| 2002 | 77.14 | 0.88 | 2.15 |
| 2003 | 66.80 | 0.75 | 2.13 |
| 2004 | 52.85 | 0.61 | 2.02 |
| 2005 | 51.91 | 0.60 | 2.08 |
| 2006 | 44.59 | 0.52 | 2.06 |
| Mean value | 59.22 | 0.67 | 2.12 |
| Std. dev. | (10.25) | (0.11) | (0.06) |

**Table 5. Pulses (grain legumes)**

| Year | Value of production, in million euros | Value per area, in million euros per 1000 stremmas | Production per area, 1000t per 1000 stremmas |
|---|---|---|---|
| 1995 | 78.23 | 1.81 | 0.29 |
| 1996 | 77.69 | 2.22 | 0.34 |
| 1997 | 68.64 | 1.98 | 0.31 |
| 1998 | 65.90 | 2.30 | 0.32 |
| 1999 | 69.66 | 2.70 | 0.35 |
| 2000 | 72.10 | 2.62 | 0.35 |
| 2001 | 81.25 | 3.63 | 0.42 |
| 2002 | 81.17 | 2.99 | 0.39 |
| 2003 | 59.60 | 2.03 | 0.36 |
| 2004 | 77.76 | 2.48 | 0.37 |
| 2005 | 71.69 | 2.22 | 0.35 |
| 2006 | 71.73 | 2.04 | 0.33 |
| Mean value | 72.95 | 2.42 | 0.35 |
| Std. dev. | (6.27) | (0.49) | (0.03) |

**Table 6. Vetches (forage and pasture crops)**

| Year | Value of production, in million euros | Value per area, in million euros per 1000 stremmas | Production per area, 1000t per 1000 stremmas |
|---|---|---|---|
| 1995 | 265.73 | 0.30 | 1.42 |
| 1996 | 271.92 | 0.32 | 1.43 |
| 1997 | 254.34 | 0.31 | 1.39 |
| 1998 | 244.55 | 0.29 | 1.37 |
| 1999 | 235.00 | 0.28 | 1.40 |
| 2000 | 258.10 | 0.31 | 1.40 |
| 2001 | 227.79 | 0.28 | 1.43 |
| 2002 | 225.89 | 0.24 | 1.41 |
| 2003 | 203.26 | 0.21 | 1.48 |
| 2004 | 194.55 | 0.20 | 1.48 |
| 2005 | 208.00 | 0.23 | 1.47 |
| 2006 | 204.36 | 0.21 | 1.47 |
| Mean value | 232.79 | 0.27 | 1.43 |
| Std. dev. | (25.32) | (0.04) | (0.04) |

**Table 7. Grapes**

| Year | Value of production, in million euros | Value per area, in million euros per 1000 stremmas | Production per area, 1000t per 1000 stremmas |
|---|---|---|---|
| 1995 | 381.40 | 0.28 | 0.69 |
| 1996 | 372.95 | 0.28 | 0.74 |
| 1997 | 356.80 | 0.27 | 0.74 |
| 1998 | 367.04 | 0.28 | 0.76 |
| 1999 | 356.81 | 0.27 | 0.74 |
| 2000 | 375.93 | 0.28 | 0.70 |
| 2001 | 412.76 | 0.31 | 0.76 |
| 2002 | 274.97 | 0.21 | 0.61 |
| 2003 | 384.21 | 0.29 | 0.74 |
| 2004 | 305.99 | 0.24 | 0.78 |
| 2005 | 323.95 | 0.26 | 0.77 |
| 2006 | 270.03 | 0.21 | 0.82 |
| Mean value | 348.57 | 0.26 | 0.74 |
| Std. dev. | (43.10) | (0.03) | (0.05) |

**Table 8. Sugar beets**

| Year | Value of production, in million euros | Value per area, in million euros per 1000 stremmas | Production per area, 1000t per 1000 stremmas |
|---|---|---|---|
| 1995 | 167.60 | 0.40 | 6.07 |
| 1996 | 163.35 | 0.41 | 6.01 |
| 1997 | 200.88 | 0.42 | 5.97 |
| 1998 | 131.42 | 0.32 | 5.34 |
| 1999 | 131.47 | 0.31 | 5.68 |
| 2000 | 169.16 | 0.35 | 6.26 |
| 2001 | 165.24 | 0.37 | 6.47 |
| 2002 | 125.00 | 0.28 | 6.44 |
| 2003 | 94.02 | 0.23 | 5.39 |
| 2004 | 94.89 | 0.26 | 6.33 |
| 2005 | 104.12 | 0.26 | 6.38 |
| 2006 | 55.38 | 0.17 | 5.83 |
| Mean value | 133.54 | 0.32 | 6.012 |
| Std. dev. | (39.75) | (0.08) | (0.37) |

We assume that the future flow of production in the absence of any external event would be the average 1990-2006. This is a working assumption since future policy and institutional changes in the EU might produce major changes in the structure of production.

### *Time to develop the new variety*

We assume that the delay between the triggering event and the development of the new variety will be 10 years and that another 5 years will pass until the new variety will become fully commercially operational.

The factors and costs shaping the capacity of a gene bank to help recovery of agricultural production are briefly presented below

A breakdown in agricultural harvest can disrupt the supply of food or feedstuff to the markets for several years following a crisis. Restoring food security following a major adverse event can be aided significantly by having a wide pool of agricultural plant genetic resources to re-introduce or engineer new plant stocks. Causes of a crisis in food availability can include natural extreme events such as droughts, disease or flooding while agricultural production can plunge also due to manmade causes such as armed conflict, political or financial crisis. For the purposes of this exercise, we will group triggers of a food crisis into two general types of events: disease and non-disease causes of a shock to food supply.

Food genetic resources held by a gene bank can help re-establish food production through breeding for improved crops following the advent of a disease. By cross combining selected plants, breeders can transfer genes with desired traits to build better crops with higher resistance to disease. The ability of a gene bank to breed disease resistant crops will vary depending on whether genetic material that can confer resistance is found within its stock. The larger the genetic pool a bank conserves, the bigger the probability that traits with desired properties will be identified.

Even if a desired trait is located by experts, the breeding of a novel variety will require significant periods of time that can stretch up to 12 years[10] using modern breeding technologies. The time needed to breed new varieties has decreased over the recent past. Use of molecular markers techniques allows breeders to monitor progress in conferring desired traits into a new variety more effectively, thus leading

[10] This is based on personal communication with officers of the GGB.

to a decrease of about 5 years in the time needed to engineer a crop today as compared to a couple of decades ago.

A shock in food security can result from causes other than disease, such as a conflict leading to a breakdown in seed supply, disruption in farming and sharp decrease in agriculture's ability to produce food. In case of a major rupture in agricultural and seed production, the ability to restore farming can depend on having a critical mass of seed material, which can be used to generate new stocks. In this case the role of a gene bank can be valuable in offering an initial stock of seeds and expanding seed supplies to meet growers' needs. The time period needed to re-develop seed stock to restore agricultural activity can extend to about five years.

Local gene banks can help to sustain food security through providing human expertise needed to convert existing genetic resources into new stocks of agricultural products. Experts at a national gene bank who are familiar with local crop varieties are more capable of screening through extensive amounts of genetic information to pick necessary material for development of disease resistant crops. Similarly, faced with a shortage in seed supply, local staff are in a better position to grow seed to meet targets for recovery of production. Therefore there is an intrinsic value to having a local gene bank that stems from having the resources, both genes and experts, needed to convert resources into solutions for sustained food security. This advantage can also be seen in terms of lowering the amounts of time needed for a gene bank to respond to crisis and provide ways of setting agricultural activity back on track.

Breeding new varieties to overcome agricultural shocks also entails costs. In a recent study by Hein and Gatzweiler (2005) on the economic value of coffee genetic resources, costs of breeding programs have been indicated to range from 300,000 (Van der Vossen and Walyaro, 1980) to 2 million USD per year (Bertrand, 2005; Van der Vossen, 2005) for programs involving collaboration of multiple research institutes and use of modern biotechnological tools.

### *The choice of the discount rate*

Policy makers need access to information concerning the discount rate of various future choices in order to make decisions concerning policy, including environmental policy. Yet the choice of the proper discount rate for calculating present values is an open issue in economic theory. Stavins (2005) notes that:

*“Choosing the discount rate to be employed in an analysis can be difficult, particularly where impacts are spread across a large number of years involving more than a single generation. In theory, the social discount rate could be derived by aggregating the individual time preference rates of all parties affected by a policy. Evidence from market behavior and from experimental economics indicates that individuals may employ lower discount rates for impacts of larger magnitude, higher discount rates for gains than for losses, and rates that decline with the time span being considered. In particular, there has been support for the use of hyperbolic discounting and similar approaches with declining discount rates over time), but most of these approaches are subject to time inconsistency.*

This discussion is beyond the scope of the present study. In our calculations we use a 5 per cent discount rate in real terms. This value is suggested by the European Commission (EC, 2008) as a benchmark real financial discount rate. The EC also suggest as real social discount rate (SDR) benchmark values: (i) 5.5 per cent for Cohesion countries, and for convergence regions elsewhere with high growth outlook; (ii) 3.5 per cent for Competitiveness regions.

We choose to use the financial discount rate of 5 per cent since we estimate insurance and productivity values in the context of financial analysis using market data. It should be noted that use of more complicated discount structures with declining discount rates would not change the qualitative characteristics of our results.

In Tables 9-15 we present the estimated expected insurance values for the seven crops of interest contained within the collection of the GGB.

**Table 9. Expected insurance value (million €): wheat**

| | Probability of Triggering Event | | |
|---|---|---|---|
| Year of Triggering Event | 10% | 20% | 40% |
| 45 | 58.75 | 119.64 | 235.00 |
| 60 | 22.01 | 44.82 | 88.04 |
| 80 | 13.57 | 27.63 | 54.27 |

**Table 10. Expected insurance value (million €): tobacco**

| | Probability of Triggering Event | | |
|---|---|---|---|
| Year of Triggering Event | 10% | 20% | 40% |
| 45 | 43.09 | 87.76 | 172.38 |
| 60 | 16.14 | 32.87 | 64.57 |
| 80 | 9.95 | 20.67 | 39.81 |

**Table 11: Expected insurance value (million €): white cabbage**

| | Probability of Triggering Event | | |
|---|---|---|---|
| Year of Triggering Event | 10% | 20% | 40% |
| 45 | 10.27 | 20.93 | 41.11 |
| 60 | 3.85 | 7.85 | 15.40 |
| 80 | 2.37 | 4.83 | 9.49 |

**Table 12. Expected insurance value (million €): pulses**

| | Probability of Triggering Event | | |
|---|---|---|---|
| Year of Triggering Event | 10% | 20% | 40% |
| 45 | 12.66 | 25.78 | 50.65 |
| 60 | 4.74 | 9.66 | 18.97 |
| 80 | 2.92 | 5.95 | 11.70 |

**Table 13. Expected insurance value (million €): vetches**

| | Probability of Triggering Event | | |
|---|---|---|---|
| Year of Triggering Event | 10% | 20% | 40% |
| 45 | 40.40 | 80.27 | 161.60 |
| 60 | 15.13 | 30.82 | 60.54 |
| 80 | 9.33 | 19 | 37.32 |

**Table 14. Expected insurance value (million €): grapes**

| | Probability of Triggering Event | | |
|---|---|---|---|
| Year of Triggering Event | 10% | 20% | 40% |
| 45 | 60.49 | 123.19 | 241.99 |
| 60 | 22.66 | 46.15 | 90.65 |
| 80 | 13.97 | 28.45 | 55.89 |

**Table 15. Expected insurance value (million €): sugar beets**

| | Probability of Triggering Event | | |
|---|---|---|---|
| Year of Triggering Event | 10% | 20% | 40% |
| 45 | 23.17 | 47.20 | 92.70 |
| 60 | 8.68 | 17.68 | 89.11 |
| 80 | 5.35 | 10.90 | 21.41 |

To provide a clearer picture of the results, Figure 19 provides the insurance value surface for wheat.

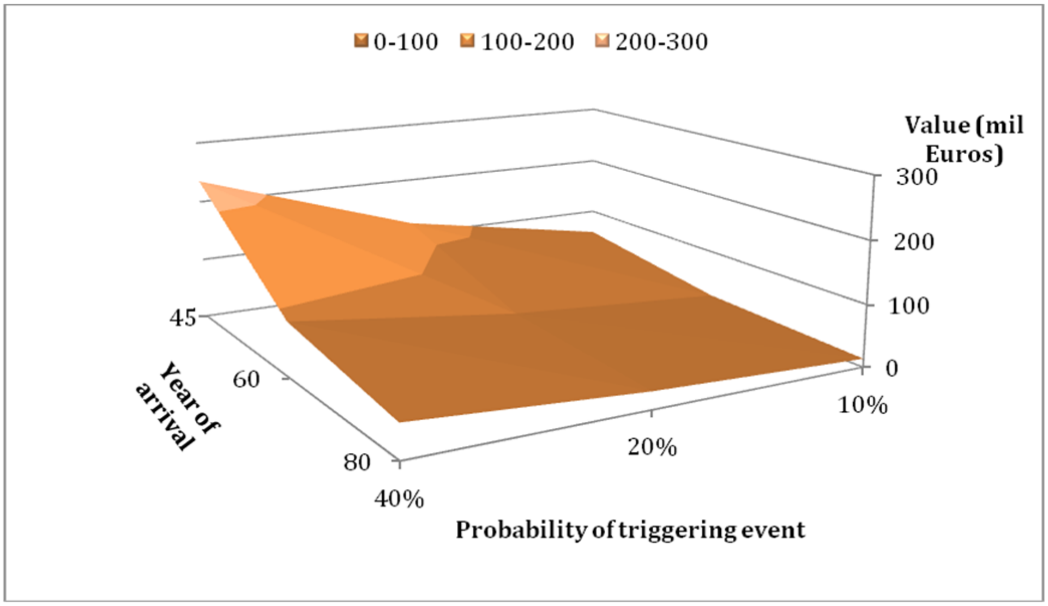



**Figure 19**. Insurance value surface: wheat

The surface indicates that the insurance value attains its largest value at the pessimistic scenario (year of arrival of the triggering event 45, probability of arrival 40 per cent), and its lowest value at the optimistic scenario (year of arrival of the triggering event 80, probability of arrival 10 per cent). The whole surface can be regarded as a piecewise approximation of the insurance value provided by the GGB by helping to develop improved varieties to counter shocks in food production, plotted against a range of years and probabilities of occurrence.

The insurance surface for the rest of the varieties has a similar shape, structure and interpretation.

Figure 20 presents the insurance surface for vetches.

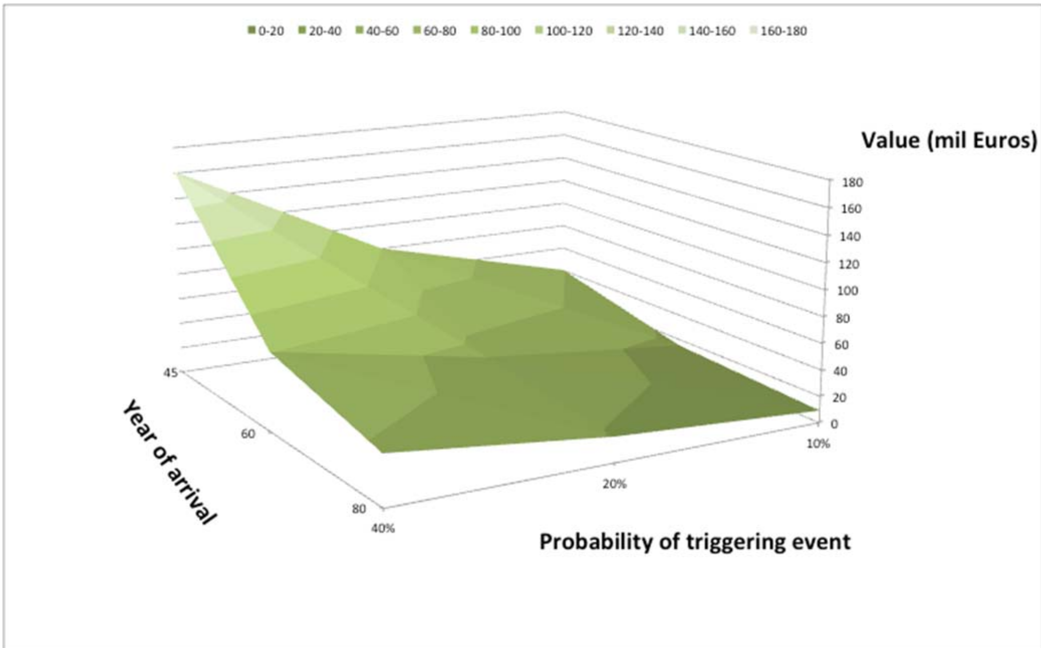



**Figure 20**. Insurance value surface: vetches

Changes in our basic assumptions about the values of the parameters will shift the surface either upwards, increasing the insurance value, or downwards, reducing the insurance value. Therefore:

- A reduction in the discount rate will uniformly increase insurance values for all accessions and vice versa.
- An increase in the probability of arrival of the triggering event for any given year will uniformly increase insurance values for all accessions and vice versa.
- A longer the delay in arrival of the triggering event for any given arrival probability will uniformly reduce insurance values for all accessions and vice versa.
- A reduction in the recovery parameter $\theta$, or in the value of the affected production, will uniformly reduce insurance values for all accessions and vice versa.
- An increase in the time required to provide a new variety once the triggering event arrives will uniformly reduce insurance values for all accessions and vice versa.

It should be noted that since the cost of developing the new variety when a triggering events arrives has not been accounted for, these values should be understood as gross expected insurance values.

On the other hand a very simple benefit-cost rule would indicate that the operation of the GGB can be justified if costs associated with maintaining the GGB are lower than the insurance value offered by the Bank. The present study has estimated that the insurance values offered by seven crops of interest held by the Bank range from 55 million euros under the optimistic scenario to 995 million euros under the pessimistic scenario, in present value terms.

The equivalent annual value, at a 5 per cent discount rate, is 2.95 million euros for the pessimistic case and 54.5 million euros for the optimistic case (values, in present value terms, are in constant 2005 euros). Note that the equivalent annual value is calculated such that the present value of the annual flow equals the estimated aggregate insurance value.

**Productivity value**

To apply the methodology regarding the productivity values stemming from the GGB, we need two types of information: (i) the increase in productivity of a specific variety due to the R&D activities of the GGB, and (ii) the probability of success in developing crops with increased productivity after the first trial in the research process.

Regarding the first type of information, we consider a uniform 10 per cent increase in average production (1995-2006) per stremma for all varieties. The increased production was valued at the corresponding average prices in constant 2005 euros for the same period. The choice of 10 per cent is arbitrary and reflects a preference for the conservative hypothesis concerning potential benefits of genetic material. For instance, research efforts of the Greek Cereal Institute in the 1980s resulted in the release of improved yield varieties which led to an increase in productivity of about 20 per cent. On the other hand, improvement of wheat varieties by the Greek Cereal Institute led to an approximately threefold increase in national wheat production over the period 1930-1970, enabling increased needs for this basic bread crop to be met successfully.

The probability of success was set at 0.0000129 which is the value used by Simpson et al. (1996), while the R&D cost was set at a level that allowed the productivity enhancement process to be profitable, the implicit assumption being that if the process is not profitable at market prices, no R&D activity will be undertaken. The productivity value was also estimated for three additional success probabilities: 0.000028, 0.000064, and 0.00011, and for the number of accessions held for each of the analyzed varieties held by the GGB.

Figures 21-27 relate the increase in the value in agricultural production following a successful development of an improved variety, with values of success probabilities at the first trial.

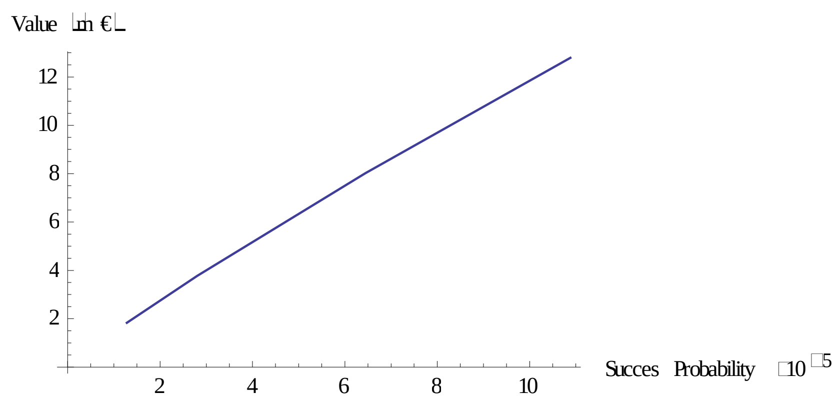



**Figure 21.** Wheat

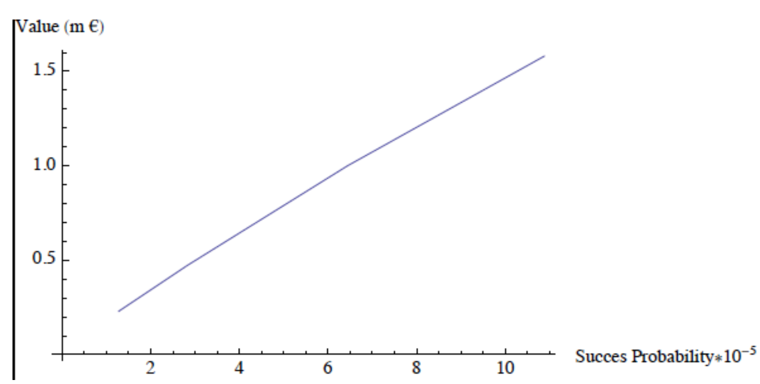



**Figure 22**. Tobacco

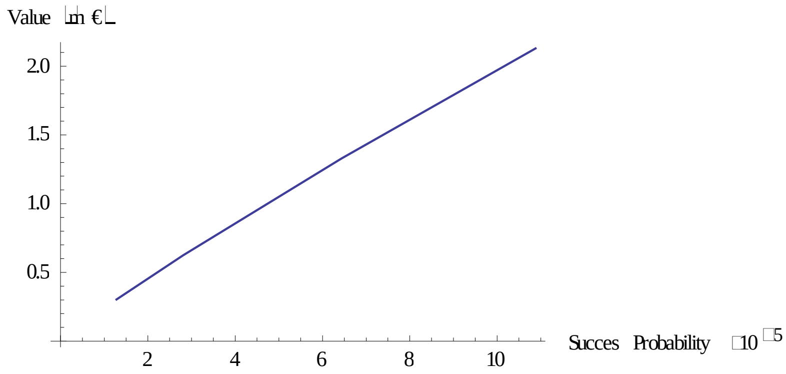



**Figure 23**. White cabbage

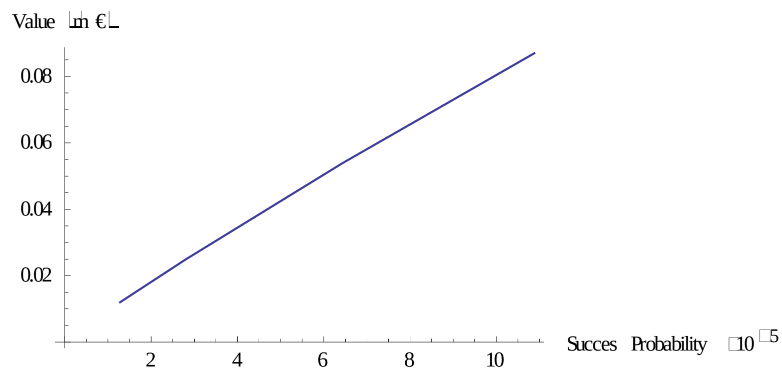



**Figure 24.** Pulses

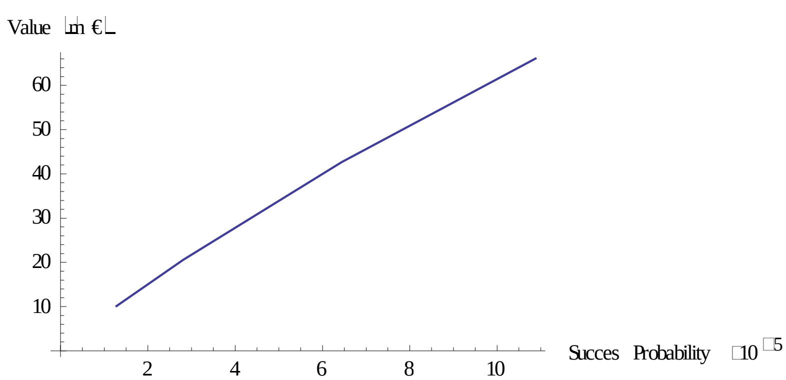



**Figure 25.** Vetches

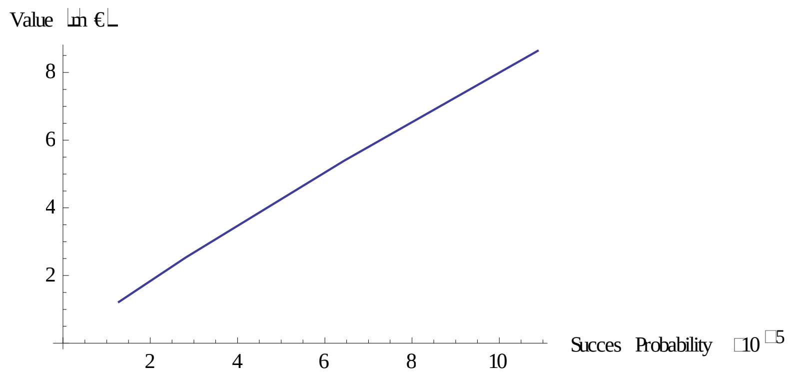



**Figure 26.** Grapes

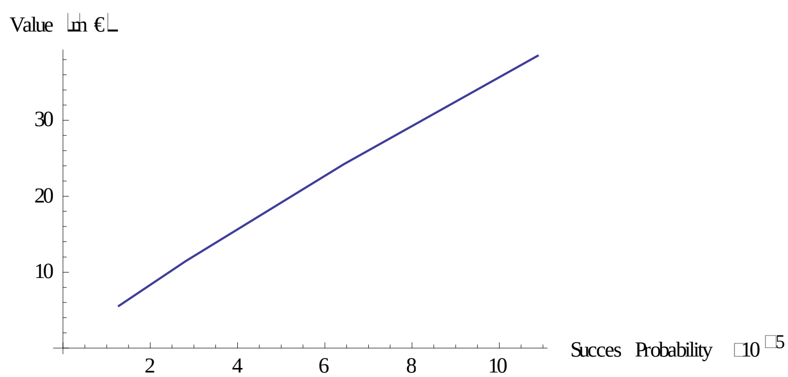



**Figure 27.** Sugar Beets

As expected productivity values increase with the success probability. Furthermore:

- An increase in the attained productivity enhancement from the initial choice of 10 per cent will shift the value curves upwards and vice versa.
- An increase in the number of the accessions for the specific variety will shift the value curves upwards and vice versa.
- An increase in the cost of R&D will shift the value curves downwards and vice versa.

The overall picture is that, under conservative assumptions, the GGB can generate positive net productivity values. In the "worst case" where the success probability at the first sampling takes its lowest value of 0.0000129, the productivity value ranges from a minimum of 0.012 million euros for pulses to a maximum of 10.13 million euros for vetches. These "minimum productivity values" for the seven commercial varieties which correspond to the GGB accessions are shown in the Table 16.

**Table 16. Productivity values**

| Commercial variety | Productivity value (million €)* |
|---|---|
| Wheat | 1.83 |
| Tobacco | 0.23 |
| Pulses | 0.012 |
| White Cabbage | 0.303 |
| Vetches | 10.13 |
| Grapes | 1.22 |
| Sugar Beets | 5.57 |

(*) Minimum productivity values as defined above

These values provide some indication of the areas toward which R&D aiming at enhancing productivity should be directed.

## 5. CONCLUDING REMARKS

As noted at the beginning of this section, values associated with the Greek Gene Bank could include, in addition to the insurance and productivity values, values associated with world agriculture and international cooperation, information values, and existence values. These values are hard to estimate since direct markets for the services provided by ex-situ conservation through a gene bank are missing. On the other hand, intuition and common sense suggest that these values exist and could be large. Drucker et al. (2005) put forward an argument which suggests that since the costs of ex-situ conservation (gene banks) is relatively easy to calculate and it seems "… *to be lower than any sensible lower-bound estimate of benefits, undertaking the expensive and challenging exercise of benefits estimation is not necessary."*

In this study we did not take this point of view, not only because this is the first attempt to assign values to the GGB and therefore to set some kind of a value benchmark, but also because, at least for insurance and productivity, we feel that by using market data we can obtain a good approximation of these values. Thus although we did not attempt to estimate non-use existence values and information values due to the large uncertainties involved, as well as values associated with world agriculture due to the "small country" characteristics of Greece, we used market values of commercial varieties which correspond to accessions held by the GGB, in order to estimate insurance and productivity values. We think that the discipline provided by market data is a good basis for providing reliable estimates. Although the values emerging from this study are also subject to uncertainties, we feel that the methodology that was developed combined with sensitivity analysis provides an approximation, at least in the first order, of the true underlying values.

Given that climate change in Greece is likely to trigger events through which the insurance value of the GGB will be realized, while knowledge accumulation might induce productivity enhancements, the values estimated by this study can be regarded as an indication of the values associated with the Greek Gene Bank. It should be understood however that a triggering event or a productivity breakthrough, should they occur, would be associated not with all, but with some of the accessions held by the GGB. Therefore the estimated values should be understood as providing a range of the values emerging from the GGB. These values could be further increased, even by small amounts, if we also account for the wider set of values associated with the GGB.

Finally, a cost benefit comparison based on the results of this study confirms that the benefits of the GGB, even with the conservative estimation adopted within the current framework, significantly exceeds the costs of its operation. Thus in terms of insurance values generated by the GGB, the flow of annual equivalent values were estimated to represent a minimum of 2.95 million euros whereas operating costs of the GGB currently correspond to less than 3 per cent[11] of this amount on an annual basis. Hence the present study suggests that maintaining and further developing the GGB is an economically justified strategy.

[11] This is based on personal communication with officers of the GGB quoting costs currently standing in the order of 100,000 euro annually.

## REFERENCES

Alcamo, J. et al. 2007. Europe., in M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, (eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, 541-580

Altieri M.A. and L. C. Merrick. 1987. In situ conservation of crop genetic resources through maintenance of traditional farming systems. Economic Botany. 41:1, 86-96.

Altieri, M.A. 1999. The ecological role of biodiversity in agroecosystems. Agriculture, Ecosystems and Environment 74, 19–31.

Anderson, P.K., et al. 2004, Emerging infectious diseases of plants: pathogen pollution, climate change and agrotechnology drivers, Trends Ecol. Evil. Vol. 19, pp. 535-544.

Baker, R.H.A. et al., 2000, The role of climatic mapping in predicting the potential distribution of non-indigenous pests under current and future climates, Agric. Ecosyst. Environ. Vol. 82, pp. 57-71.

Bank of Greece. 2011. A report on the environmental, economic and social impacts of climate change in Greece. Report prepared by the Climate Change Impacts Study Committee.

Bertrand, B. 2005. (Coffee breeder, CIRAD, Montpellier France).

Boughey, C.L. 1981. Evolutionary and taxonomic studies in wild and cultivated beets. PhD thesis, University of Birmingham, UK.

Cocks, P.S. 1999. Reproductive strategies and genetic structure of wild and naturalised legume populations. *In*: Bennett S.J., Cocks P.S. (eds). Genetic Resources of Mediterranean Pasture and Forage Legumes. Dordrecht, The Netherlands: Kluwer Academic Publishers. pp. 20–31.

Commission on Genetic Resources for Food and Agriculture (CGR). 2011. Coping with climate change: the importance of genetic resources for food security.

Drucker, A., Smale, M., and P. Zambrano, (2005), Valuation and Sustainable Mamagement of Crop and Livestock Biodiversity: A Review of Applied Economics Literature, CGIAR System-wide Genetic Resources Programme (SGRP).

Duc, G., Bao, S., Baum, M., Redden, B., Sadiki, M., Suso, M.J., Vishniakova, M. and Zong, X. 2008. Diversity maintenance and use of *vicia faba* L. genetic resources. Field Crops Res, doi: 10.1016/j.fcr.2008.10.003.

Esquinas-Alcazar J. 2005. Protecting crop genetic diversity for food security: political, ethical and technical challenges. Nature 6, 946-953.

European Commission (EC), Directorate General Regional Policy, (2008), Guide to Cost Benefit Analysis of investment projects. Structural Funds, Cohesion Fund and Instrument for Pre-Accession.

FAO and the Platform on Agrobiodiversity Research. 2010. Biodiversity for Food and Agriculture. Contributing to food security and sustainability in a changing world.

FAO Commission on Genetic Resources for Food and Agriculture. 2010. *The Second Report on the State of the World's Plant Genetic Resources*. Rome.

FAO. 1997. The First Report on the State of the World's Plant Genetic Resources. Rome.

Fischer, R., Stoger, E., Schillberg, S., Christou, P. and Twyman, R. M. (2004) Plant-based production of biopharmaceuticals. Curr. Opin. Plant Biol., 7:152-158.

Frese, L. 2002. Combining static and dynamic management of PGR: a case study of *Beta* genetic resources. In: Engels J.M.M., Ramanatha Rao V., Brown A.H.D., Jackson M.T. (eds.). Managing Plant Genetic Diversity. IPGRI, Rome, pp. 133-147.

Friebe, B., Jiang, J., Raupp, W.J., McIntosh, R.A. and Gill, B.S. 1996. Characterization of wheat alien translocations conferring resistance to diseases and pests. Current status. Euphytica 91: 59-87.

Gepts, P. 2006. Plant Genetic Resources Conservation and Utilization: The Accomplishments and Future of a Societal Insurance Policy. Crop Science. 46:5, 2278-2292.

Gomez–Campo, C. 1999. Biology of Brassica coenospecies. Elsevier Science, The Netherlands.

Gray, A.R. 1982. Taxonomy and evolution of broccoli (*Brassica oleracea* var. *italica*). Econ. Bot., 36 (4): 397-410.

Gómez-Campo, C. and Gustafsson, M. 1991. Germplasm of wild n=9 Mediterranean species of *Brassica*. Botanika Chronika: 10, 429-434.

Hajjar, R., Jarvis, D.I. and Gemmill-Herren, B. 2008. The utility of crop genetic diversity in maintaining ecosystem services. Agriculture, Ecosystems and Environment, 123: 261-270.

Hariri, D., Fouchard, M. and and Prud'homme, H. 2001. Incidence of *Soil-borne wheat mosaic virus* in mixtures of susceptible and resistant wheat cultivars, *European Journal of Plant Pathology* 107: 625–631, 2001.

Hein, Lars & Gatzweiler, Franz, 2006. The economic value of coffee (Coffea arabica) genetic resources, Ecological Economics, vol. 60(1), pages 176-185.

Iglesias, A. et al. 2007, Adaptation to climate change in the agricultural sector Report to European commission directorate General for Agriculture and Rural Development ED05334 Issue Number 1 Prepared by AEA Energy & Environment and Universidad de Politecnica de Madrid

Johns, T. and P. B. Eyzaguirre. 2006. Linking biodiversity, diet and health in policy and practice. Proceedings of the Nutrition Society, 65, 182-189. doi:10.1079/PNS2006494.

Knüpffer, H. 2009. *Triticeae* Genetic Resources in *ex situ* Genebank Collections. In: Feuillet K., Muehlbauer G.J. (eds.) Genetics and Genomics of the *Triticeae*. Plant Genetics/Genomics, vol. 7. Springer, NY, pp. 81-120.

Kumar, P. (ed). 2010. TEEB: The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations, London: Earthscan.

McGovern, P.E. 2003. Ancient Wine: The Search for the Origins of Viniculture. Princeton University Press, Princeton.

Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being. Biodiversity Synthesis. World Resources Institute, Washington, DC.

Murphy, J. P., Cox, T. S., Rufty, R. C. and Rodgers, D. M. (1987) A representation of the pedigree relationships among flue-cured tobacco cultivars. Tob. Sci., 31:70-75.

Ngugi, H. K., King, S. B., Abayo, G. O., and Reddy, Y. V. R. 2002. Prevalence, incidence, and severity of sorghum diseases in western Kenya. Plant Dis. 86: 65-70.

Opperman, C. H., Lommel, S. A., Burke, M., Carlson, J., George, C., Gove, S., Graham, S., Houfek, T.D., Kalat, S., Littlem, P.C., Lumpkin, A., Redman, L., Ross, T., Schaffer, R., Scholl, E., Stephens, P. J., Windham, E,. Zekanis, S. H., Lakey, N., Bidell, J. and Budiman, A. (2006) Update on the Tobacco Genome Initiative: A Gene Discovery Platform. Plant & Animal Genomes XIV Conference, San Diego, pp. 30.

Ordás, C. and Cartea, M.E. 2008. Cabbage and Kale. In: Prohens J., Nuez F. (Eds.), Handbook of Plant Breeding. Vegetables I. Asteraceae, Brassicaceae, Chenopodiaceae and Cucurbitaceae. Springer, USA, pp. 117-149.

Pimentel, D., Wilson, C., Mccullum, C., Huang, R., Dwen, P., Flack, J., Tran, Q., Saltman, T. and Cliff, B. 1997. Economic and environmental benefits of biodiversity, BioScience, 47, 747-757.

Purty, R.S., Kumar, G., Singla-Pareek, S.L., and Pareek, A. 2008. Towards salinity tolerance in *Brassica*: an overview. Physiol. Mol. Biol. Plants, 14: 39-49.

Rao, V.R. and T. Hodgkin. 2002. Genetic diversity and conservation and utilization of plant genetic Resources. Plant Cell, Tissue and Organ Culture 68: 1–19.

Rausser, G. C. and A. Small. 2000. Valuing research leads: bioprospecting and the conservation of genetic resources. Journal of Political Economy 108, 173-206.

Reynolds, M., Bonnett, D., Chapman, S.C., Furbank, R.T., Mane, Y., Mather, D.E. and Parry, M.A.J. 2011. Raising yield potential of wheat. I. Overview of a consortium approach and breeding strategies. Journal of Experimental Botany, Vol. 62, No. 2, pp. 439–452.

Riaz, A., Doligez, R., Henry, J., and Walker, M.A. 2007. Grape. In: C. Kole (Ed.), Genome Mapping and Molecular Breeding in Plants, Vol. 4, Fruits and Nuts, Springer-Verlag, Berlin, Heidelberg, pp. 63-101.

Rodgman, A. and Perfetti. T. A. (2008) The Chemical Components of Tobacco and Tobacco Smoke. CRC Press, Taylor and Francis Group, Boca Raton, Florida.

Secretariat of the Convention on Biological Diversity. 2010. Global Biodiversity Outlook 3, Montreal.

Shand H. (1997). Human Nature: Agricultural Biodiversity and Farm-based Food Security,Rural Advancement Foundation International, Ottawa, 1997, pp.22-23.

Simpson, D., R. Sedjo and J. Reid, Valuing Biodiversity for Use in Pharmaceutical Research, Journal of Political Economy, Vol. 104, No. 1 (Feb., 1996), pp. 163-185.

Skuras, D. and D. Psaltopoulos. 2012. A Broad Overview Of The Main Problems Derived From Climate Change That Will Affect Agricultural Production In The Mediterranean Area FAO/OECD Workshop, http://www.oecd.org/tad/sustainableagriculture/faooecdworkshopbuildingresilienceforadaptationtoclimatechangeintheagriculturesectorromeitaly23-24april2012.htm (accessed November 2012).

Smale, M and J. Hanson (2010), Assessing the Impact of CGIAR Investments in Germplasm Collection, Conservation, Characterization and Evaluation: The Scope of the Literature, http://impact.cgiar.org/sites/default/files/images/SmaleHansen2011.pdf (accessed November 2012)

Stavins, R. 2005. Environmental Economics, The New Palgrave Dictionary of Economics, 2nd Edition, Lawrence Blume and Steven Durlauf, General Editors. London: Palgrave Macmillan Ltd.

Stavropoulos, N., D. Gogkas, A. Chatziathanassiou, E. Zagilis, G. Drakopoulos, D. Paitaridou, P. Trigas R. Thanopoulos, S. Koutsomitros, A. Perdikaris, B. Lourida, and A. Alesta. 2006. Greece: Second Country Report concerning the state on plant genetic resources for food and agriculture. Hellenic Democracy, Ministry of Rural Development and Food, Athens.

Street, K., Mackay, M., Kaul, N., El Bouhssini, M., Konopka J., and Mitrofanova, O. 2008. Diving into the genepool: A rational system to access specific traits from large germplasm collections. In: Appels R., Eastwood R., Lagudah E., Langridge P., Mackay M., McIntyre L., Sharp P. (eds.), 11th International Wheat Genetics Symposium. Sydney University Press, Brisbane, Australia, paper 013.

Teshome, A., Brown, A.H.D., and Hodgkin, T. 2001. Diversity in landraces of cereal and legume crops. In: J. Janick (Ed.), Plant Breeding Reviews, John Wiley & Sons, Inc., pp. 221–261.

Van der Vossen, H.A.M. and Walyaro, D.J. 1980. Breeding for resistance to coffee berry disease in Coffea arabica L. Euphytica 29 (3), 777–791.

Van der Vossen, H.A.M., 2005. Personal communication to authors of Hein and Gatzweiler, 2005 (referenced above).

Warwick, S.I., Francis, A., and La Fleche, J. 2000. Guide to wild germplasm of *Brassica* and allied crops (tribe Brassiceae, Brassicaceae) 2nd edn. Agriculture and Agri-Food Canada Research Branch Publication, ECORC Ottawa, Canada.Contribution No. 991475. [http://www.brassica.info].

Wright, B.D. 1997. Crop genetic resource policy: the role of ex situ genebanks. The Australian Journal of Agricultural and Resource Economics, 41:1, 81-115.

Yang, B., Xiao, B., Chen, X. and Shi, C. (2007) Assessing the genetic diversity of tobacco germplasm using intersimple sequence repeat and inter-retrotransposon amplification polymorphism markers. Annals of Applied Biology, 150: 393-401.

Zhong, W. H., Zhu, C. J., Shu, M., Sun, K. D., Zhao, L., Wang, C., Ye, Z. J. and Chen, J. M. (2010) Degradation of nicotine in tobacco waste extract by newly isolated Pseudomonas sp. ZUTSKD. Bioresour. Tech., 101 (18): 6935-41.

Zhu, Y., Chen, H., Fan, J., Wang, Y., Li, Y., Chen, J., Fan, J.X., Yang, S., Hu, L., Leung, H., Mew, T.W., Teng, P.S., Wang, Z., and Mundt, C.C. 2000. Genetic diversity and disease control in rice. Nature 406: 718-722.

Zohary, D. and Hopf, M. 1993. Domestication of Plants in the Old World, Oxford University Press, Oxford.

Zohrabian, A., Traxler G., Caudill S., and Smale M. (2003) Valuing pre-commercial genetic resources: a maximum entropy approach. American Journal of Agricultural Economics 85, 429-436.

## APPENDIX

Appendix A contains statistical data and Appendix B contains the programming code in Mathematica for the estimation of insurance and productivity values.

### A. Statistical Data

The following tables present data at the national level for the years 1995 to 2006 on: area of production in 1000 stremmas; harvested production in 1000t; and annual weighted average producer prices. Individual prices were weighted by the share of sales of agricultural products for the selected varieties.[12]

#### 1. Wheat

Wheat includes the domestic production and area of both soft and hard wheat.

| Soft Wheat | | | |
|---|---|---|---|
| Year | Area[a] | Production[b] | Price[c] |
| 1995 | 2759 | 800 | 53 |
| 1996 | 2626 | 676 | 46.8 |
| 1997 | 2422 | 620 | 50.3 |
| 1998 | 2301 | 595 | 46.1 |
| 1999 | 2014 | 482 | 45.3 |
| 2000 | 1892 | 503 | 43.8 |
| 2001 | 1766 | 475 | 0.15 |
| 2002 | 1571 | 404 | 0.14 |
| 2003 | 1449 | 327 | 0.15 |
| 2004 | 1259 | 368 | 0.14 |
| 2005 | 1197 | 341 | 0.13 |
| 2006 | 1452 | 376 | 0.12 |
| [a] Area in 1000 stremmas, [b] Production in 1000 tons, [c] Price per kg | | | |

[12] Prices for the time period 1995 to 2000 are reported in drachmas per kilogram. They are converted to euros employing the fixed exchange rate of drachmas/euro 340,75.

| Hard Wheat | | | |
|---|---|---|---|
| Year | Area[a] | Production[b] | Price[c] |
| 1995 | 6029 | 1515 | 52.5 |
| 1996 | 6013 | 1410 | 45.7 |
| 1997 | 6189 | 1462 | 49.3 |
| 1998 | 6160 | 1468 | 46.5 |
| 1999 | 6252 | 1495 | 42.2 |
| 2000 | 6685 | 1783 | 44.0 |
| 2001 | 6988 | 1721 | 0.15 |
| 2002 | 7129 | 1635 | 0.15 |
| 2003 | 7029 | 1375 | 0.16 |
| 2004 | 7191 | 1724 | 0.13 |
| 2005 | 7193 | 1677 | 0.13 |
| 2006 | 6327 | 1402 | 0.12 |
| [a] Area in 1000 stremmas, [b] Production in 1000 tons, [c] Price per kg | | | |

**2. Sugar beets**

| Sugar beets | | | |
|---|---|---|---|
| Year | Area[a] | Production[b] | Price[c] |
| 1995 | 419 | 2544 | 15.0 |
| 1996 | 394 | 2367 | 17.0 |
| 1997 | 473 | 2823 | 18.5 |
| 1998 | 411 | 2196 | 16.3 |
| 1999 | 426 | 2418 | 15.2 |
| 2000 | 481 | 3011 | 16.2 |
| 2001 | 447 | 2891 | 0.05 |
| 2002 | 440 | 2833 | 0.04 |

| | | | |
|---|---|---|---|
| 2003 | 409 | 2206 | 0.04 |
| 2004 | 362 | 2291 | 0.04 |
| 2005 | 408 | 2603 | 0.04 |
| 2006 | 327 | 1905 | 0.03 |
| [a] Area in 1000 stremmas, [b] Production in 1000 tons, [c] Price per kg | | | |

### 3. Tobacco

| Tobacco, all varieties | | | |
|---|---|---|---|
| Year | Area[a] | Production[b] | Price[c] |
| 1995 | 689 | 148 | 168.32 |
| 1996 | 683 | 149 | 168.22 |
| 1997 | 668 | 148 | 169.24 |
| 1998 | 663 | 148 | 155.01 |
| 1999 | 648 | 145 | 129.05 |
| 2000 | 614 | 137 | 120.13 |
| 2001 | 618 | 142 | 123.26 |
| 2002 | 593 | 133 | 152.00 |
| 2003 | 572 | 137 | 130.00 |
| 2004 | 559 | 133 | 146.00 |
| 2005 | 544 | 125 | 128.00 |
| [a] Area in 1000 stremmas, [b] Production in 1000 tons, [c] Price per 100 kg | | | |

Tobacco includes the production and the harvested area of the main tobacco varieties found in Greek agriculture, i.e. Eastern type and Berley and Virginia. Price series for all varieties were obtained from the Eurostat[13] database.

[13] Link: www.epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database. In the absence of reliable production data for the production of Virginia and of Berley individually, aggregated Eurostat values were used.

## 4. Pulses

To obtain economic values for pulses, two commercial agricultural products were considered, namely chick peas and beans, including green and dry beans.

| Chick Peas | | | |
|---|---|---|---|
| Year | Area[a] | Production[b] | Price[c] |
| 1995 | 19 | 2 | 300.0 |
| 1996 | 17 | 2 | 385.6 |
| 1997 | 18 | 2 | 386.5 |
| 1998 | 16 | 2 | 439.3 |
| 1999 | 14 | 2 | 467.0 |
| 2000 | 14 | 2 | 454.8 |
| 2001 | 14 | 3 | 1.35 |
| 2002 | 17 | 3 | 1.36 |
| 2003 | 15 | 2 | 1.18 |
| 2004 | 21 | 3 | 1.41 |
| 2005 | 22 | 3 | 1.37 |
| 2006 | 23 | 3 | 1.34 |
| [a] Area in 1000 stremmas, [b] Production in 1000 tons, [c] Price per kg | | | |
| Beans | | | |
| Year | Area[a] | Production[b] | Price[c] |
| 1995 | 123 | 23 | 513.5 |
| 1996 | 123 | 27 | 423.2 |
| 1997 | 120 | 24 | 421.5 |
| 1998 | 117 | 23 | 398.4 |
| 1999 | 117 | 24 | 422.2 |
| 2000 | 111 | 23 | 508.5 |
| 2001 | 107 | 22 | 1.39 |
| 2002 | 105 | 22 | 1.49 |
| 2003 | 98 | 22 | 1.47 |
| 2004 | 87 | 20 | 1.64 |
| 2005 | 88 | 19 | 1.61 |
| 2006 | 94 | 19 | 1.78 |
| [a] Area in 1000 stremmas, [b] Production in 1000 tons, [c] Price per kg | | | |

5. Vetches

| Vetches | | | |
|---|---|---|---|
| Year | Area[a] | Production[b] | Price[c] |
| 1995 | 213,00 | 78,00 | 57.60 |
| 1996 | 207,00 | 76,00 | 65.10 |
| 1997 | 201,00 | 72,00 | 73.10 |
| 1998 | 189,00 | 66,00 | 65.30 |
| 1999 | 180,00 | 63,00 | 61.00 |
| 2000 | 178,00 | 66,00 | 74.90 |
| 2001 | 168,00 | 59,00 | 0.21 |
| 2002 | 169,00 | 57,00 | 0.14 |
| 2003 | 170,00 | 63,00 | 0.09 |
| 2004 | 164,00 | 63,00 | 0.08 |
| 2005 | 168,00 | 64,00 | 0.16 |
| 2006 | 217,00 | 83,00 | 0.13 |
| [a] Area in 1000 stremmas, [b] Production in 1000 tons, [c] Price per kg | | | |
| | | | |
| Other clovers, i.e. Alfa-alfa | | | |
| Year | Area[a] | Production[b] | Price[c] |
| 1995 | 1193,00 | 1253,00 | 44.70 |
| 1996 | 1121,00 | 1193,00 | 52.00 |
| 1997 | 1122,00 | 1157,00 | 52.60 |
| 1998 | 1121,00 | 1141,00 | 54.60 |
| 1999 | 1109,00 | 1167,00 | 53.00 |
| 2000 | 1121,00 | 1158,00 | 60.00 |
| 2001 | 1086,00 | 1168,00 | 0.16 |
| 2002 | 1142,00 | 1230,00 | 0.16 |
| 2003 | 1115,00 | 1234,00 | 0.15 |
| 2004 | 1112,00 | 1219,00 | 0.15 |
| 2005 | 1138,00 | 1236,00 | 0.16 |
| 2006 | 1228,00 | 1334,00 | 0.15 |
| [a] Area in 1000 stremmas, [b] Production in 1000 tons, [c] Price per kg | | | |

6. Brassica

| Cabbage | | | |
|---|---|---|---|
| Year | Area[a] | Production[b] | Price[c] |
| 1995 | 89 | 195 | 71.1 |
| 1996 | 91 | 193 | 50.9 |
| 1997 | 89 | 187 | 89.7 |
| 1998 | 90 | 188 | 79.5 |
| 1999 | 90 | 189 | 93.0 |
| 2000 | 91 | 197 | 94.9 |
| 2001 | 88 | 196 | 0.31 |
| 2002 | 88 | 189 | 0.37 |
| 2003 | 89 | 190 | 0.33 |
| 2004 | 87 | 176 | 0.29 |
| 2005 | 86 | 179 | 0.29 |
| 2006 | 86 | 177 | 0.26 |
| [a] Area in 1000 stremmas, [b] Production in 1000 tons, [c] Price per kg | | | |

7. Total grapes and vines

To obtain the economic value of production for total grapes and raisins, the types of grapes shown in the table below were used.

| Total Grapes and Vines | | | | | |
|---|---|---|---|---|---|
| Year | Area[a], total | Production[b] grapes made into wine | Production [b] grapes for table use | Production [b] raisins | Production [b] total |
| 1995 | 1376 | 657.492 | 215.669 | 77.593 | 950.754 |
| 1996 | 1352 | 693.835 | 219.767 | 89.471 | 1003.073 |
| 1997 | 1336 | 683.797 | 222.700 | 85.866 | 992.363 |
| 1998 | 1334 | 673.449 | 253.760 | 92.573 | 1019.782 |
| 1999 | 1323 | 665.504 | 222.872 | 85.731 | 974.107 |
| 2000 | 1327 | 633.025 | 208.663 | 84.715 | 926.403 |
| 2001 | 1321 | 665.902 | 249.445 | 94.492 | 1009.839 |
| 2002 | 1318 | 561.405 | 185.822 | 58.831 | 806.058 |
| 2003 | 1312 | 681.659 | 218.781 | 69.656 | 970.096 |
| 2004 | 1258 | 680.673 | 214.713 | 82.532 | 977.918 |
| 2005 | 1264 | 707.762 | 189.213 | 76.722 | 973.697 |
| 2006 | 1261 | 711.387 | 245.573 | 79.249 | 1036.209 |
| [a] Area in 1000 stremmas, [b] Production in 1000 tons | | | | | |

The corresponding prices shown in the table below were used.

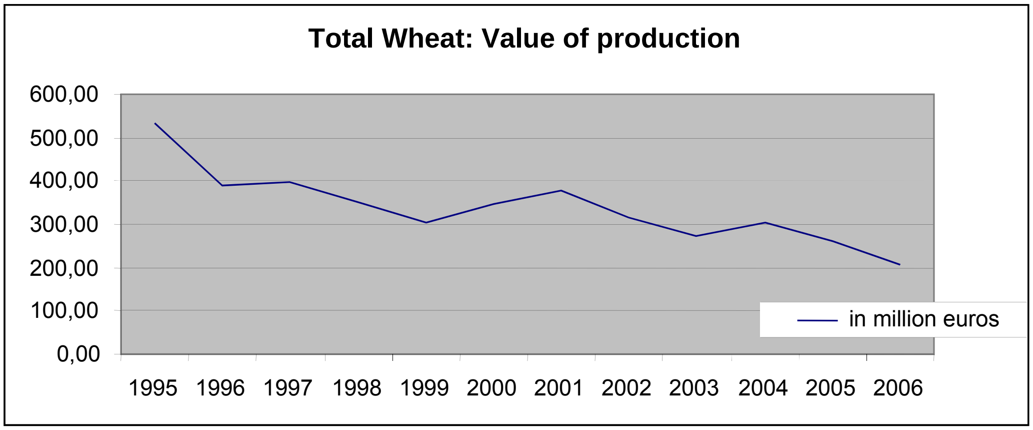
| Total Grapes and Vines | | | | |
|---|---|---|---|---|
| Year | Price[c] table grapes consumed fresh | Price[c] Currants | Price[c] Sultanas | Price[c] wine grapes |
| 1995 | 111.4 | 266.4 | 157.2 | 80.7 |
| 1996 | 127.8 | 169.9 | 167.8 | 84.2 |
| 1997 | 160.0 | 168.4 | 187.2 | 83.3 |
| 1998 | 161.4 | 247.1 | 173.0 | 88.7 |
| 1999 | 176.4 | 265.5 | 161.0 | 83.6 |
| 2000 | 212.5 | 288.5 | 159.9 | 106.4 |
| 2001 | 0.58 | 0.84 | 0.43 | 0.29 |
| 2002 | 0.56 | 0.75 | 0.38 | 0.24 |
| 2003 | 0.64 | 0.82 | 0.51 | 0.31 |
| 2004 | 0.42 | 0.62 | 0.38 | 0.28 |
| 2005 | 0.55 | 0.49 | 0.36 | 0.31 |
| 2006 | 0.47 | 0.47 | 0.30 | 0.25 |
| [c] Price per kg | | | | |

Notes on Data

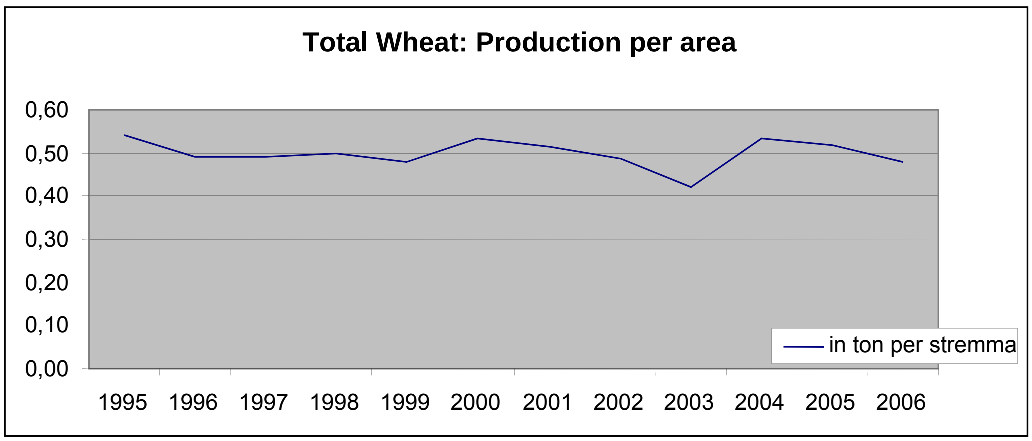
The GGB is a genetic collection capturing almost the entire genetic variability available in domestic crop species. The significant species in that collection are the species for which the GGB holds major genetic material with research potential and unique characteristics. Within each category the most significant commercial crops were chosen in terms of their economic value in Greek agricultural. Discussion with experts and a literature review narrowed the collection of species to be analyzed in this study.

Seven agricultural crop categories were chosen for analysis: 1) Wheat (soft and hard wheat), 2) White Cabbage (Brassicas), 3) Sugar beets, 4) Vines, including grapes and raisins (currants and sultanas) for table use and wine production, 5) Pulses including beans (green and dry) and chick peas, 6) Tobacco (Eastern type, Berley and Virginia) and 7) Pasture grasses (vetch and other cloves, i.e. Alfa and alfa etc.)

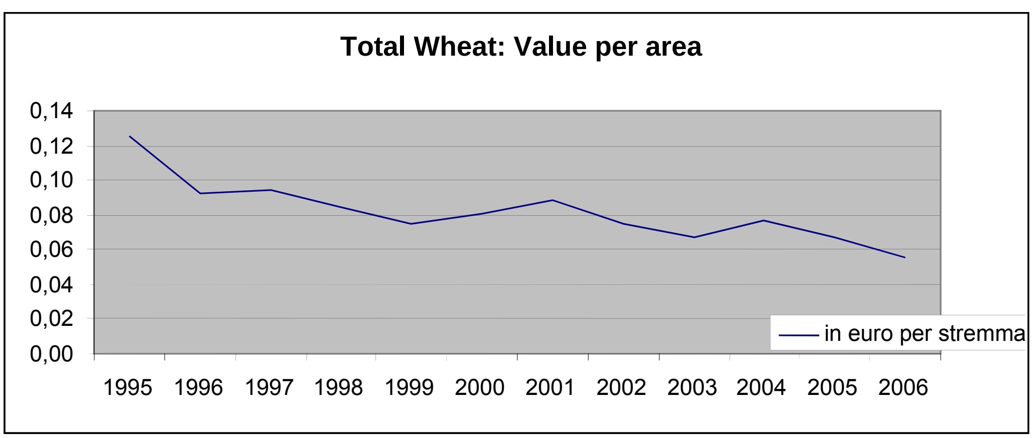
## Graphs



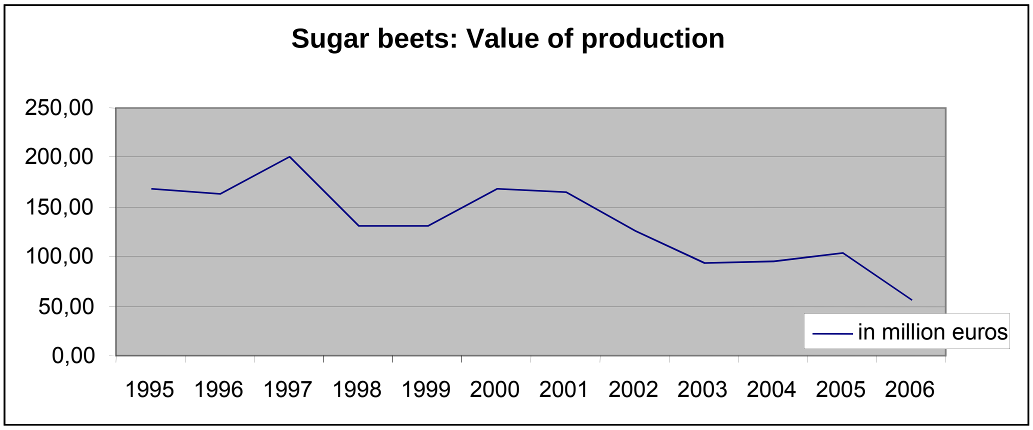
Total Wheat: Value of production
600,00
500,00
400,00
300,00
200,00
100,00
0,00
in million euros
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006

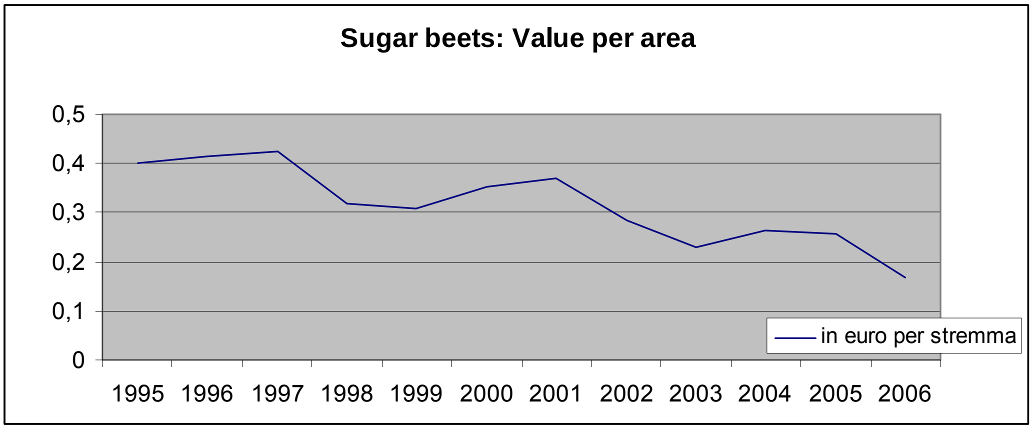



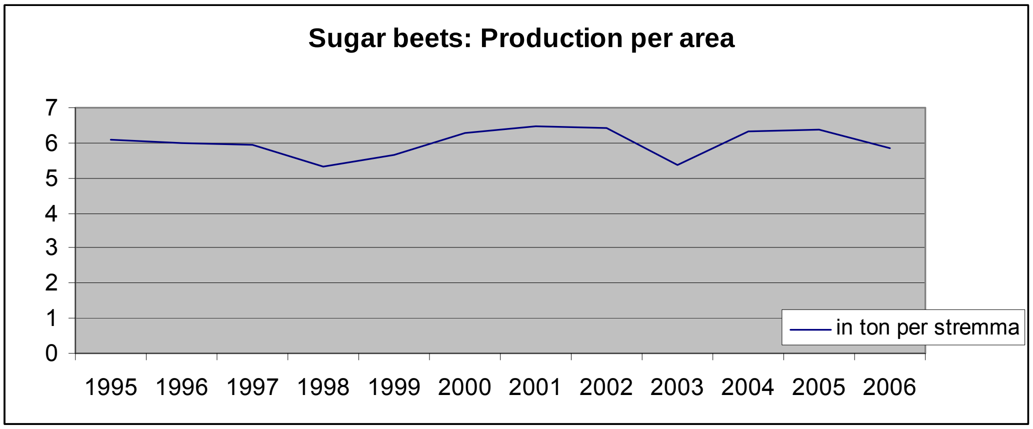
Total Wheat: Production per area
0,60
0,50
0,40
0,30
0,20
0,10
0,00
in ton per stremma
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006

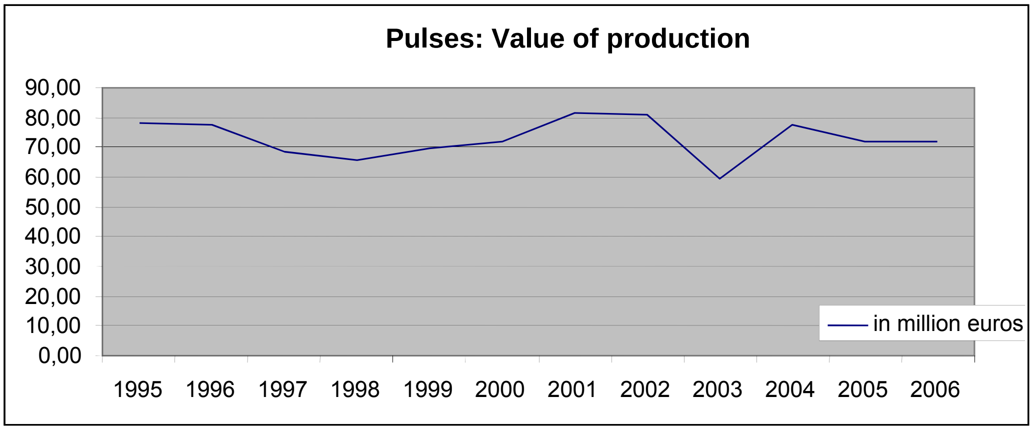



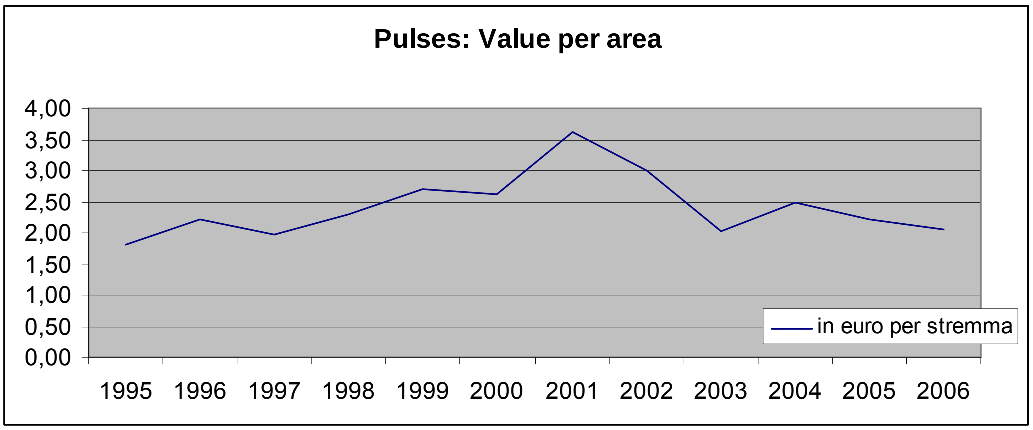
Total Wheat: Value per area
0,14
0,12
0,10
0,08
0,06
0,04
0,02
0,00
in euro per stremma
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006

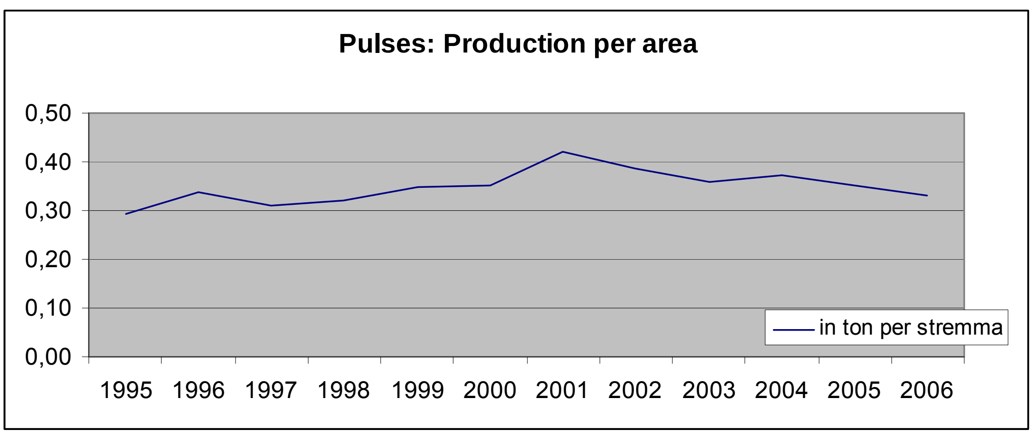

Sugar beets: Value of production
250,00
200,00
150,00
100,00
50,00
0,00
in million euros
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006

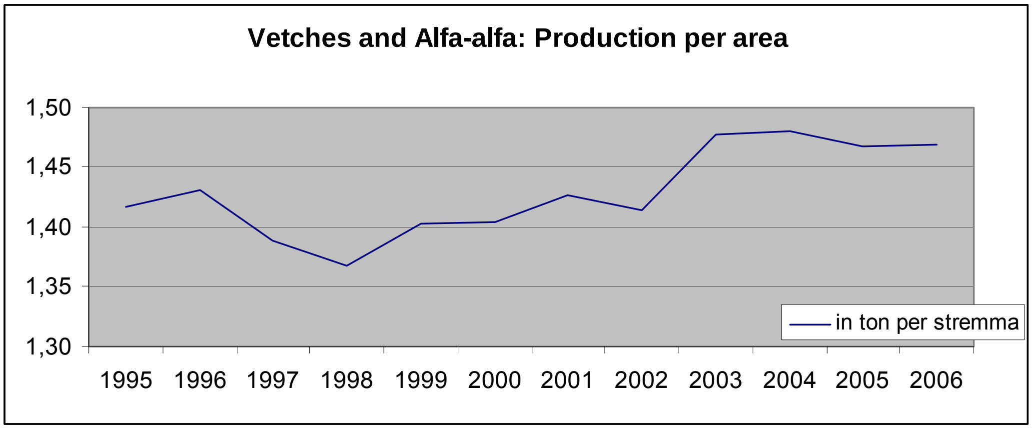

Sugar beets: Value per area
0,5
0,4
0,3
0,2
0,1
0
in euro per stremma
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006

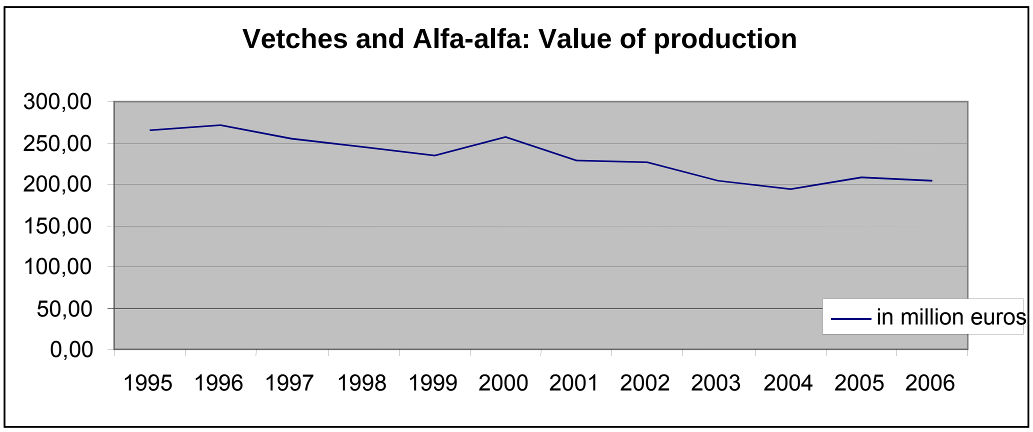

Sugar beets: Production per area
7
6
5
4
3
2
1
0
in ton per stremma
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006

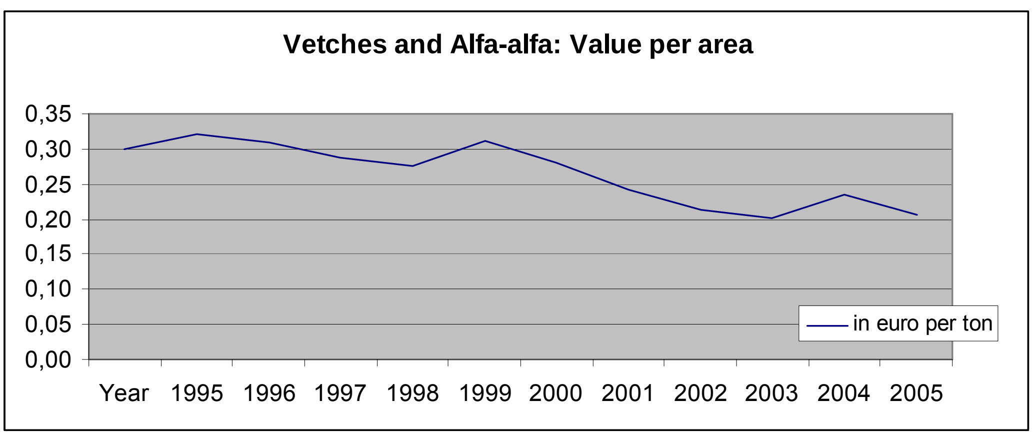

Pulses: Value of production
90,00
80,00
70,00
60,00
50,00
40,00
30,00
20,00
10,00
0,00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
in million euros

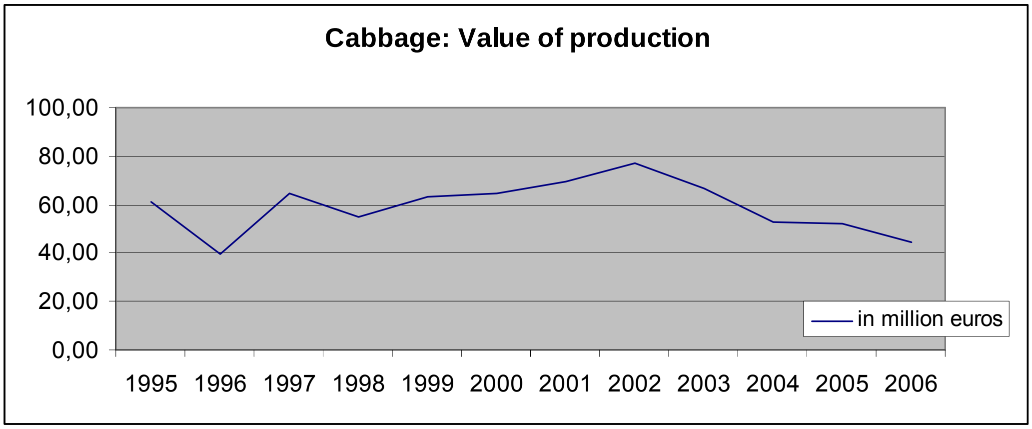

Pulses: Value per area
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
in euro per stremma

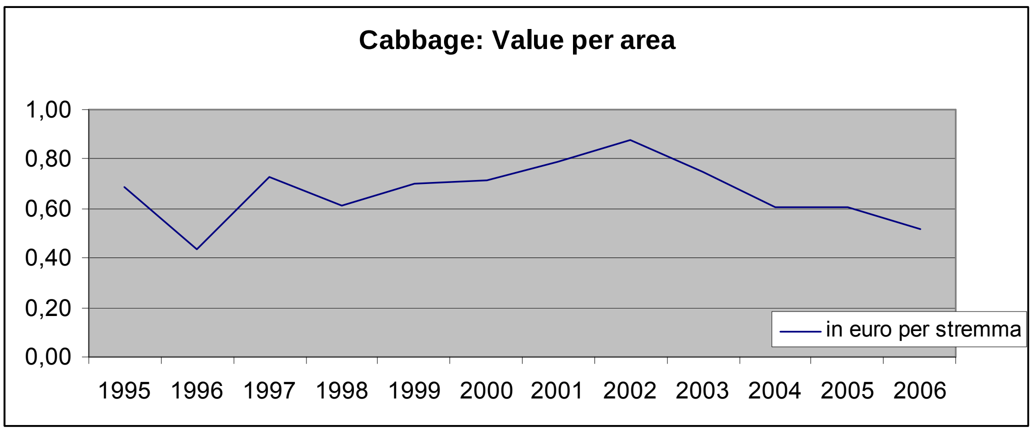

Pulses: Production per area
0,50
0,40
0,30
0,20
0,10
0,00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
in ton per stremma

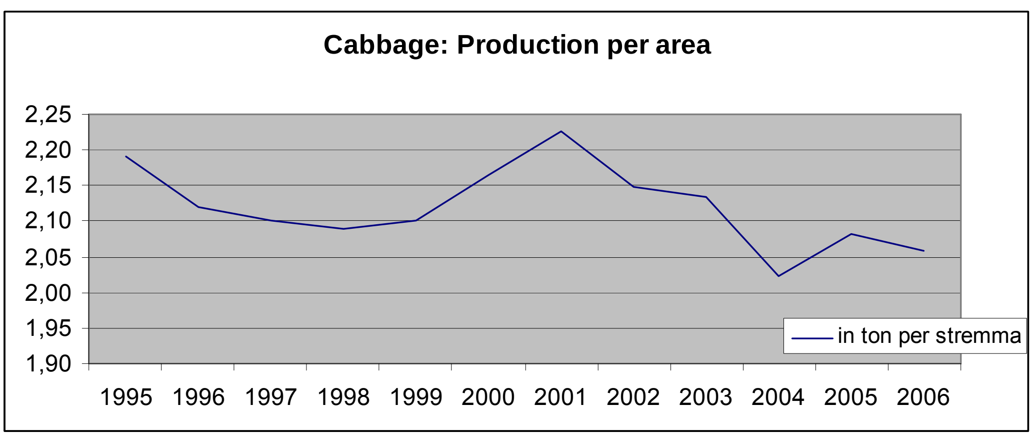

Vetches and Alfa-alfa: Production per area
1,50
1,45
1,40
1,35
1,30
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
in ton per stremma

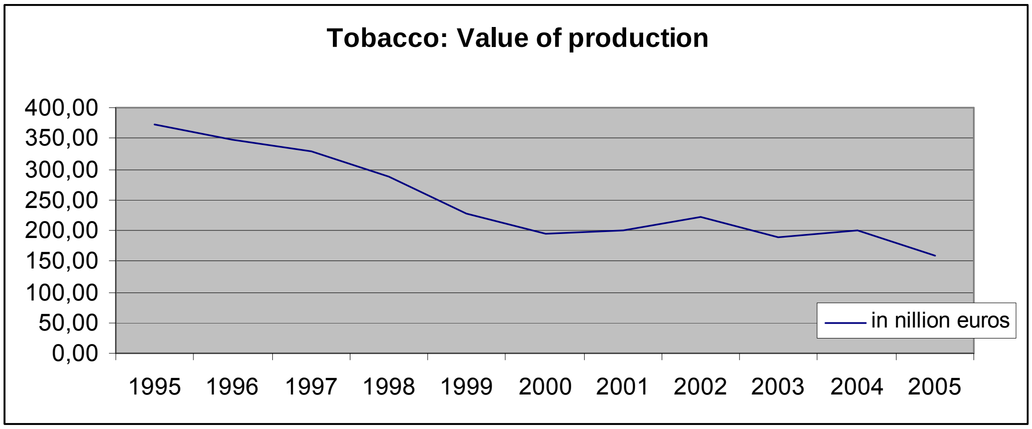

Vetches and Alfa-alfa: Value of production
300,00
250,00
200,00
150,00
100,00
50,00
0,00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
in million euros

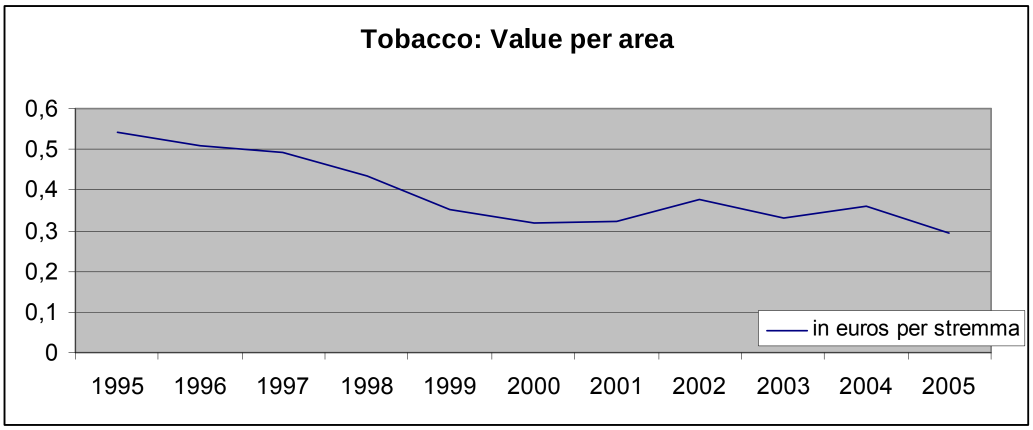

Vetches and Alfa-alfa: Value per area
0,35
0,30
0,25
0,20
0,15
0,10
0,05
0,00
Year 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005
in euro per ton

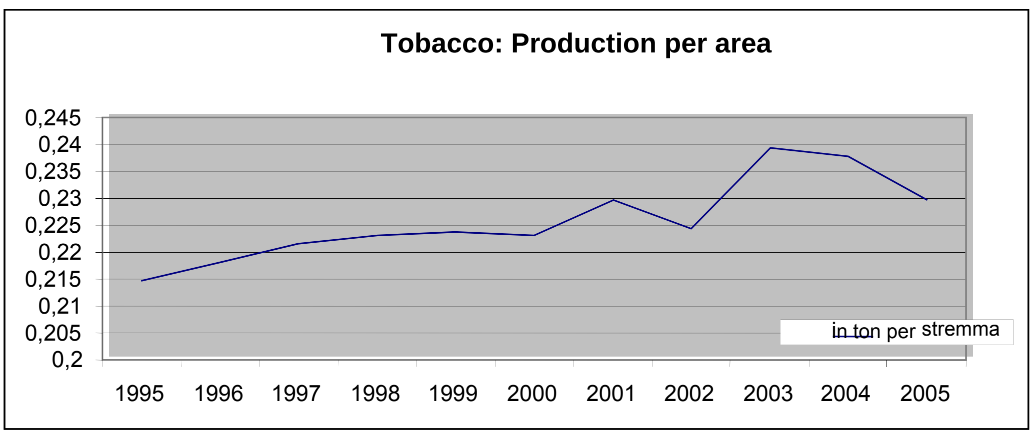

Cabbage: Value of production
100,00
80,00
60,00
40,00
20,00
0,00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
in million euros

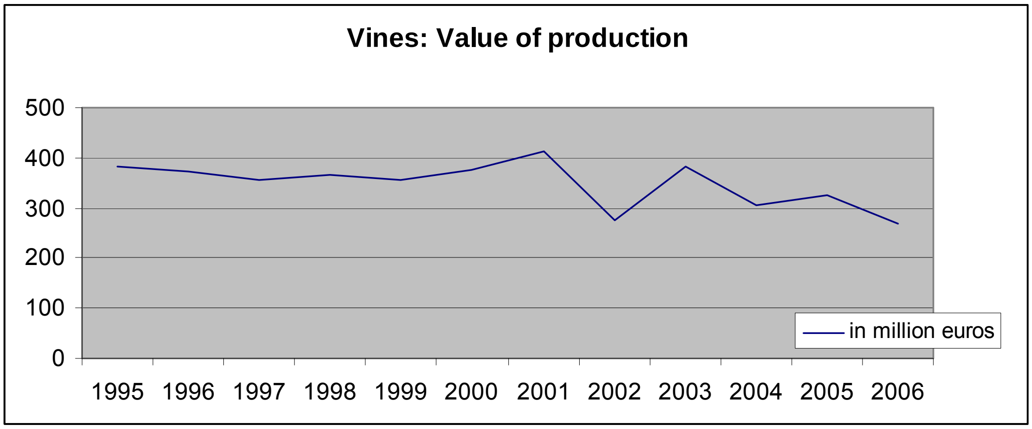

Cabbage: Value per area
1,00
0,80
0,60
0,40
0,20
0,00
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
in euro per stremma

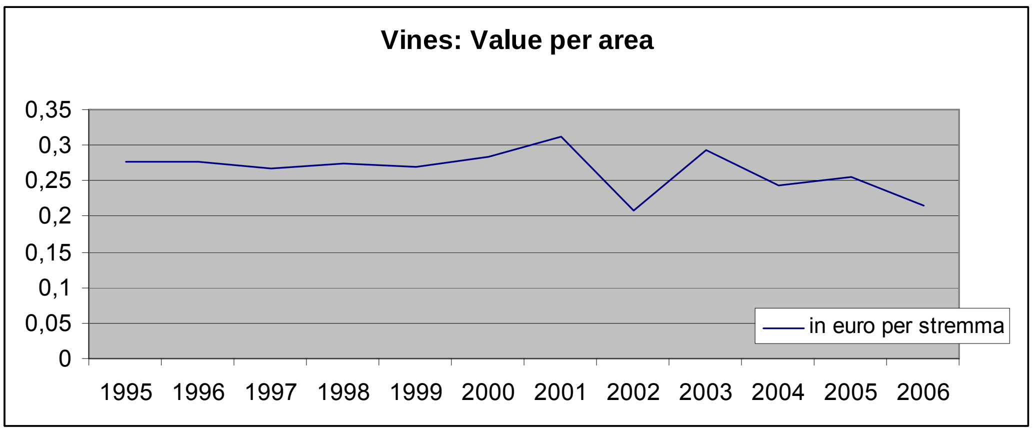

Cabbage: Production per area
2,25
2,20
2,15
2,10
2,05
2,00
1,95
1,90
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
in ton per stremma

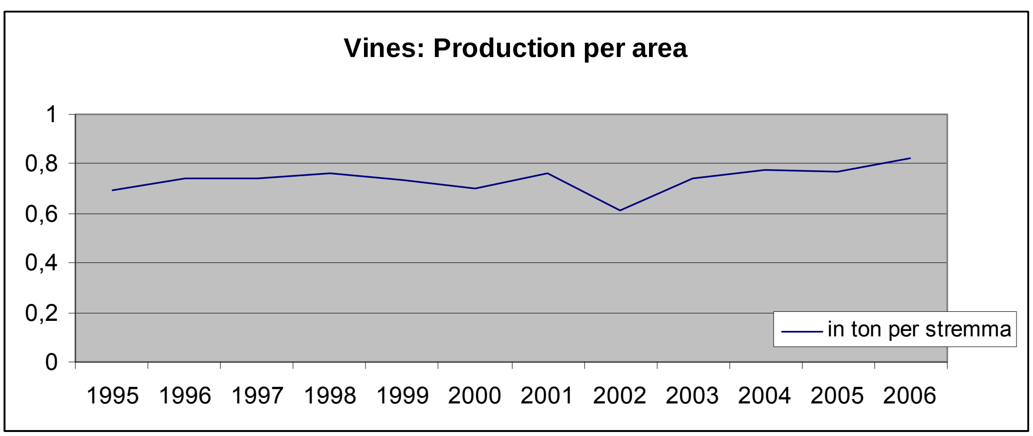

Tobacco: Value of production
400,00
350,00
300,00
250,00
200,00
150,00
100,00
50,00
0,00
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
in nillion euros


Tobacco: Value per area
0,6
0,5
0,4
0,3
0,2
0,1
0
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
in euros per stremma


Tobacco: Production per area
0,245
0,24
0,235
0,23
0,225
0,22
0,215
0,21
0,205
0,2
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
in ton per stremma


Vines: Value of production
500
400
300
200
100
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
in million euros


Vines: Value per area
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
in euro per stremma


Vines: Production per area
1
0,8
0,6
0,4
0,2
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
in ton per stremma

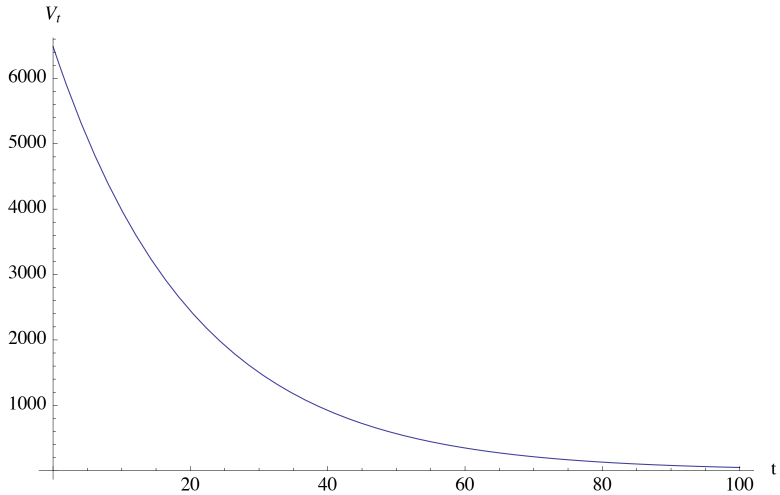
## B. Programming Code

### Calculation of Insurance Value for Wheat

```
(* Insurance Value Wheat*)
(*Scenario:
 45-40. We expect the arrival of an event that will make necessary the use of
   the gene bank to recover wheat production 45 years from now or latter.The
   probability of having this event 45 years from now or latter is 40 %*)
```

Present value of recovered losses

```
(* Determine the present value now of losses at t. Assumed annual
  value of wheat 338.51 mil euros which the average 1995-2006*)
(*Time horizon is 50 years*)
R = 338.51; i = 0.05; T = 50;
v[t_] = Sum[R / (1 + i) ^ (t + tau), {tau, 0, T - 1}];
Plot[v[t], {t, 0, 100}, AxesLabel → {"t", "Vt"}]
```




```
v[0]
```

```
6488.8
```

```
(* 6488.8 means that the present value now of losing NOW (t=0)
 the wheat production for the next 50 years is 6488.8 mil euros*)
v[
 10]
```

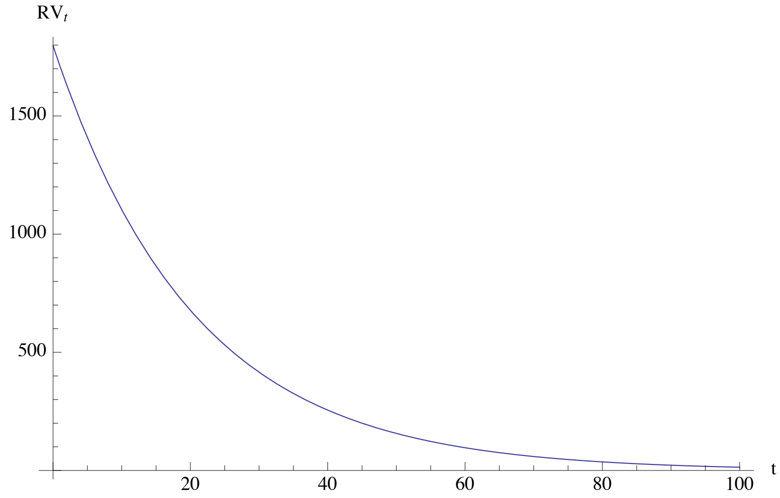
```
3983.56
```

```
(* 3983.56 means that the present value now of losing after 10 years
 (t=10)the wheat production for the next 50 years is 3983.56 mil euros*)
```

Present value of recovered losses

```
(* Present value of the recovered losses from the bank. It takes 10 years to
 develop the equivalent variety and another five year to recover full
 production. the recovery during the five years is assumed linear*)
theta = 0.5;
rcvry[t_] = theta * (1 / ((1 + i) ^ (t + 10))) *
   ((1 / 5) * R + (2 / 5) * (R / (1 + i)) + (3 / 5) * (R / (1 + i) ^ 2) +
     (4 / 5) * (R / (1 + i) ^ 2) + Sum[R / (1 + i) ^ (4 + tau), {tau, 0, T - 5}]);
```

```
Plot[rcvry[t], {t, 0, 100}, AxesLabel → {"t", "RVt"}]
```




```
rcvry[0]
```

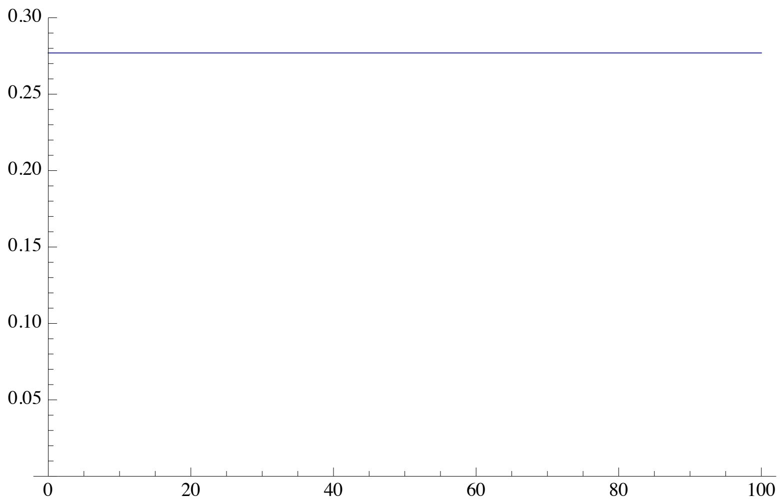
1797.22

```
rcvry[10]
```

1103.34

```
(* 1103.34 means that the present value
  now of the recovered by the bank value of losing at t=
 10 the wheat production for the next 50 years is 1103.34 mil euros*)
```

```
Plot[rcvry[t] / v[t], {t, 0, 100}, PlotRange → {0, 0.3}]
```



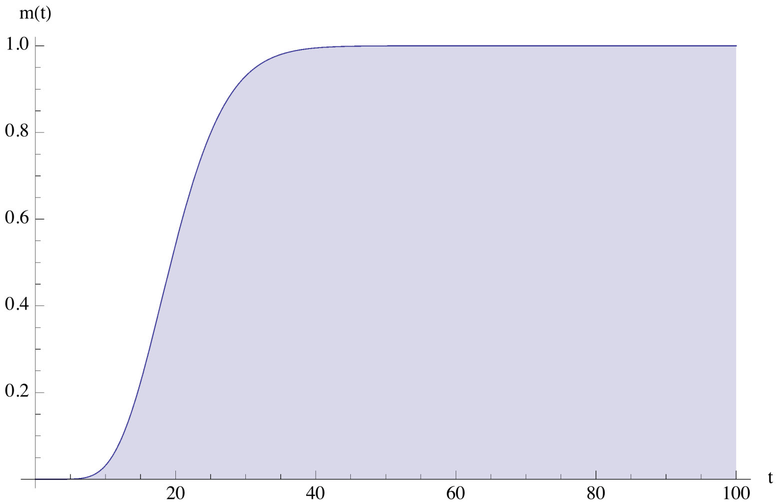
# Poisson arrivals

```
(*Poisson Distribution*)
m2[t_] = Evaluate@Table[CDF[GammaDistribution[10, 2], t]]
p[t_, k_] = (((((m2[t])^k) * Exp[-m2[t]]) / k!)) * 1.1;
p[t_, 1]
```

$$\begin{cases} \text{GammaRegularized}\left[10, 0, \frac{t}{2}\right] & t > 0 \\ 0 & \text{True} \end{cases}$$

$$1.1\, e^{-\left(\begin{cases} \text{GammaRegularized}\left[10,0,\frac{t\_}{2}\right] & t\_>0 \\ 0 & \text{True} \end{cases}\right)} \left(\begin{cases} \text{GammaRegularized}\left[10, 0, \frac{t\_}{2}\right] & t\_ > 0 \\ 0 & \text{True} \end{cases}\right)$$

```
Plot[m2[t], {t, 0, 100}, AxesLabel → {"t", "m(t)"}, Filling → Axis]
```




```
N[m2[20]]
```

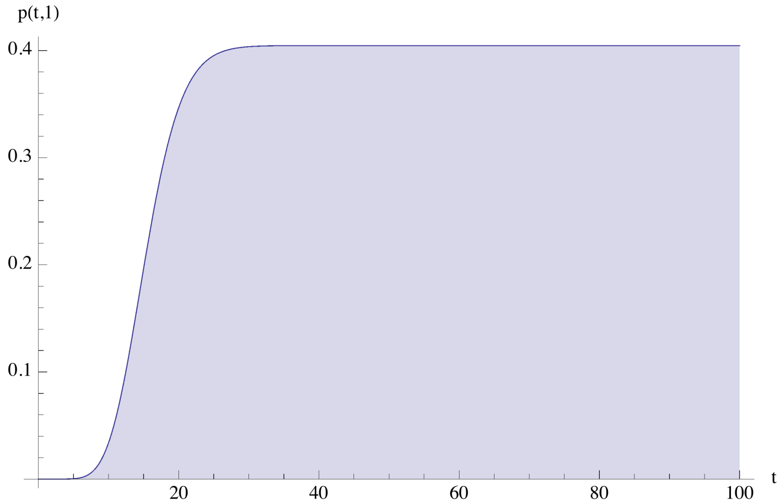
0.54207

```
(* 0.54207 means that 20 year from now we expect
 the arrival of approximately 'half' destructive event*)
N[m2[40]]
```

0.995005

```
(* 0,995 means that 40 year from now we
 expect the arrival of 'all' the triggering event*)
```

```
Plot[p[t, 1], {t, 0, 100}, AxesLabel → {"t", "p(t,1)"}, Filling → Axis]
```




```
N[p[10, 1]]
```

0.0339141

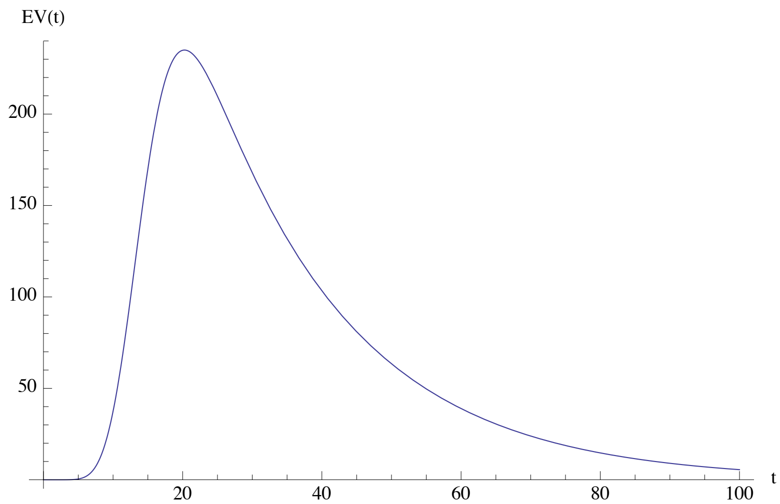
```
(* 0.0339 means that the probability of having
 the destructive event 10 years from now is 3%*)
N[p[45, 1]]
```

0.404667

```
(* 0.404 means that the probability of having the destructive event 45
  years from now is 40.4% and remains approximately constant after
  that. It remain constant because we have assumed that we expect
  the arrival of the destructive event in 40-45 years from now*)
```

## Expected insurance benefits

```
(* Present value now of Expected Insurance benefits at t=0,1,2,...*)
q0 = 1; q1 = 0;
q[t_] = q0 * Exp[q1 * t];
b[t_, k_] = p[t, 1] * rcvry[t];
Plot[b[t, 1], {t, 0, 100}, AxesLabel → {"t", "EV(t)"}]
```



```
b[10, 1]
37.4186
b[4, 1]
0.0756225
FindMaximum[b[t, 1], {t, 20}]
{235.003, {t → 20.2626}}
(*Expected benefits from the bank = 235 mil euros*)
```

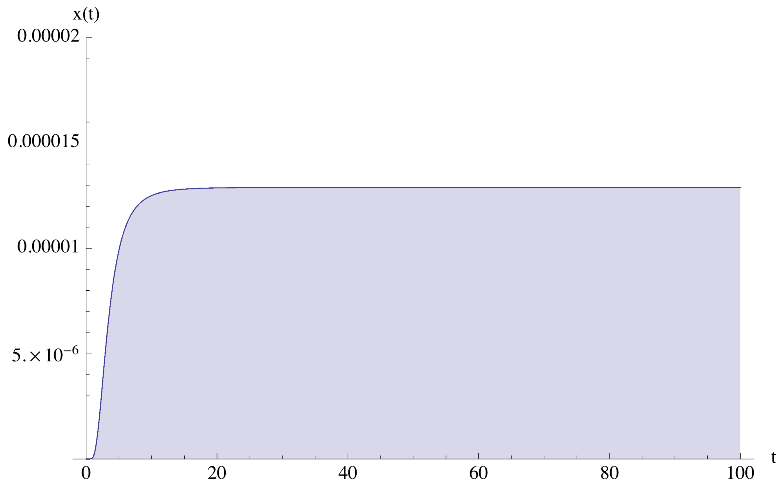
# Calculation of Productivity Gains

```
(* Productivity gains Wheat*)
```

## Probability of success in enhancing productivity

```
ClearAll
x = Beta[t / (1 + t), 16, 5];
Plot[x, {t, 0, 100}, PlotRange → {0, 0.00002},
 AxesLabel → {"t", "x(t)"}, Filling → Axis]
N[Beta[40 / (1 + 40), 16, 5]]
```

```
ClearAll
```



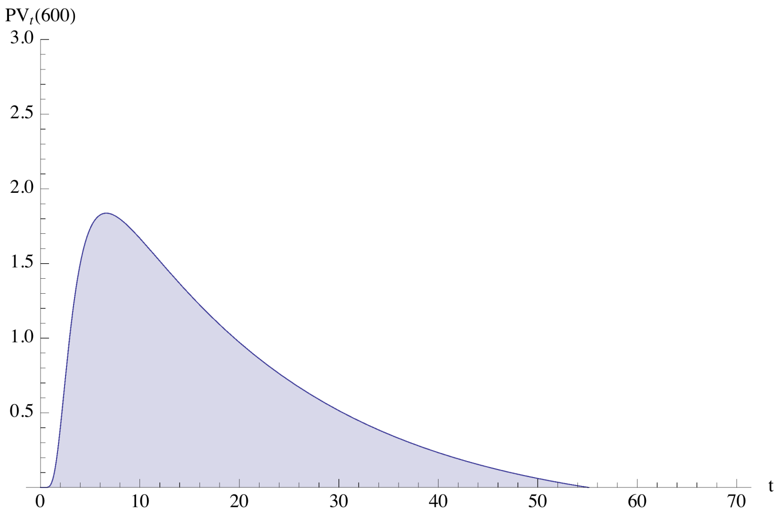

```
0.0000128986
```

```
1.28986264881215358 * 10^-5
```

```
0.0000128986264881215358
```

# Productivity value

```
(*Productivity Value*)
z = 34.728622; c = 0.8 * z * x; n = 600; g = 0; T = 50; i = 0.05;
w[t_] = Sum[z / ((1 + i) ^ (t + tau + 10)), {tau, 0, T - 1}];
pv[t_] = (((x * w[t] - c) / x) (1 - (1 - x) ^ n));
Plot[pv[t], {t, 0, 70}, AxesLabel → {"t", "PVt(600)"},
 PlotRange → {0, 3}, Filling → Axis]
FindMaximum[pv[t], {t, 6}]
```

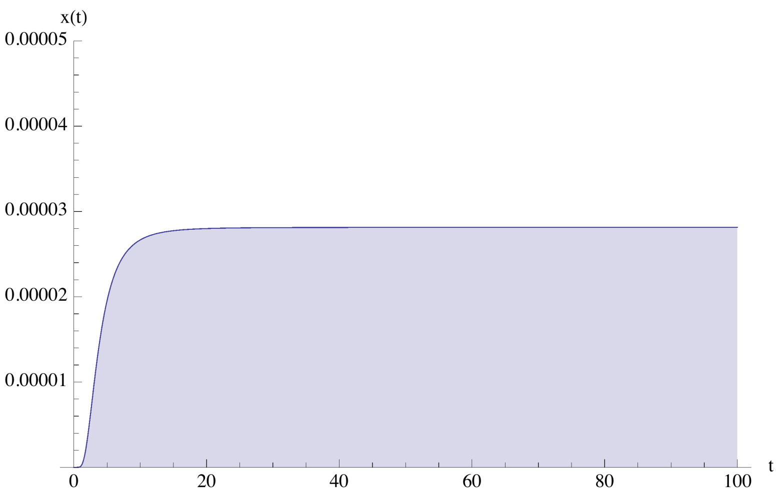



```
{1.83704, {t → 6.62001}}
```

# Productivity value for different success probabilities

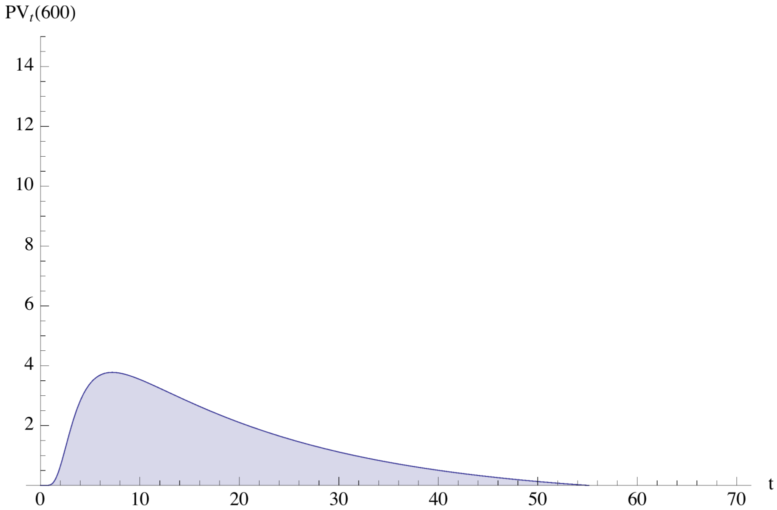
```
ClearAll
x = Beta[t / (1 + t), 16, 4.5];
Plot[x, {t, 0, 100}, PlotRange → {0, 0.00005},
 AxesLabel → {"t", "x(t)"}, Filling → Axis]
N[Beta[40 / (1 + 40), 16, 4.5]]
```

```
ClearAll
```




```
0.000028126
```

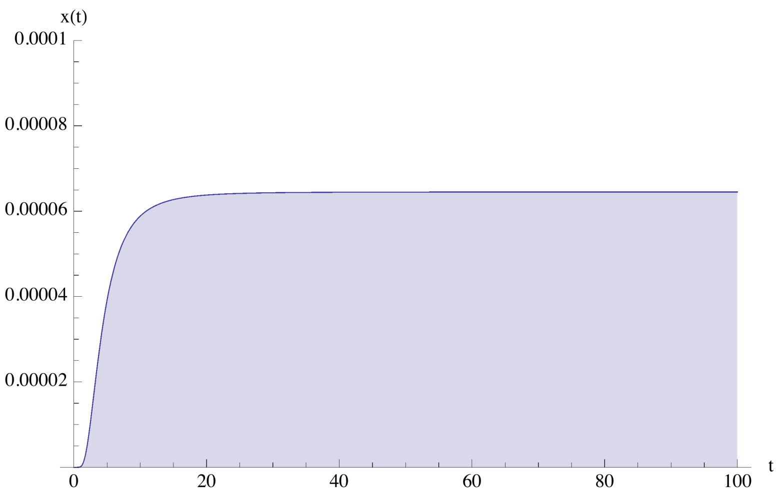
```
(*Productivity Value*)
z = 34.728622; c = 0.8 * z * x; n = 600; g = 0; T = 50; i = 0.05;
w[t_] = Sum[z / ((1 + i) ^ (t + tau + 10)), {tau, 0, T - 1}];
pv[t_] = (((x * w[t] - c) / x) (1 - (1 - x) ^ n));
Plot[pv[t], {t, 0, 70}, AxesLabel → {"t", "PVt(600)"},
 PlotRange → {0, 15}, Filling → Axis]
FindMaximum[pv[t], {t, 6}]
```




```
{3.7783, {t → 7.21723}}
```

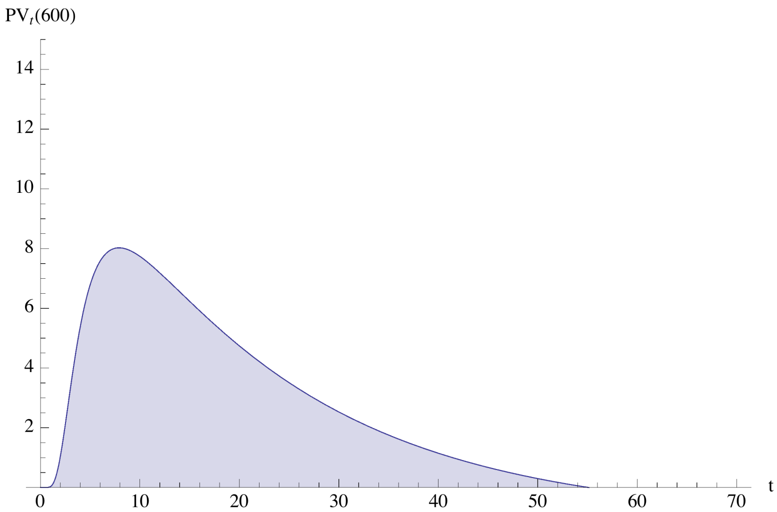
```
ClearAll
x = Beta[t / (1 + t), 16, 4];
Plot[x, {t, 0, 100}, PlotRange → {0, 0.0001},
 AxesLabel → {"t", "x(t)"}, Filling → Axis]
N[Beta[40 / (1 + 40), 16, 4]]
```

```
ClearAll
```




```
0.0000644335
```

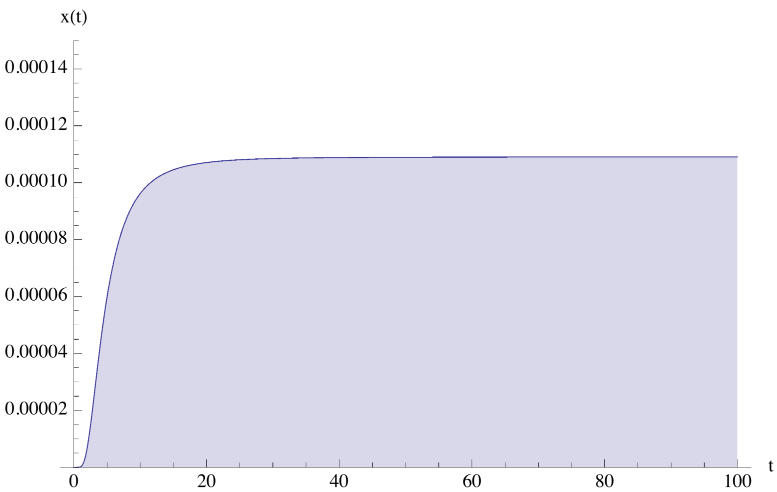
```
(*Productivity Value*)
z = 34.728622; c = 0.8 * z * x; n = 600; g = 0; T = 50; i = 0.05;
w[t_] = Sum[z / ((1 + i) ^ (t + tau + 10)), {tau, 0, T - 1}];
pv[t_] = (((x * w[t] - c) / x) (1 - (1 - x) ^ n));
Plot[pv[t], {t, 0, 70}, AxesLabel → {"t", "PVt(600)"},
 PlotRange → {0, 15}, Filling → Axis]
FindMaximum[pv[t], {t, 7}]
```




```
{8.02533, {t → 7.90197}}
```

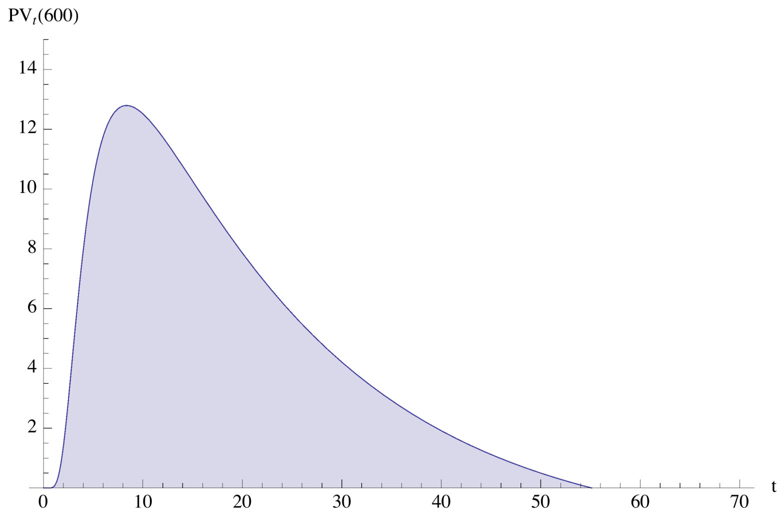
```
ClearAll
x = Beta[t / (1 + t), 16, 3.7];
Plot[x, {t, 0, 100}, PlotRange → {0, 0.00015},
 AxesLabel → {"t", "x(t)"}, Filling → Axis]
N[Beta[40 / (1 + 40), 16, 3.7]]
```

```
ClearAll
```




```
0.000108832
```

```
(*Productivity Value*)
z = 34.728622; c = 0.8 * z * x; n = 600; g = 0; T = 50; i = 0.05;
w[t_] = Sum[z / ((1 + i) ^ (t + tau + 10)), {tau, 0, T - 1}];
pv[t_] = (((x * w[t] - c) / x) (1 - (1 - x) ^ n));
Plot[pv[t], {t, 0, 70}, AxesLabel → {"t", "PVt(600)"},
 PlotRange → {0, 15}, Filling → Axis]
FindMaximum[pv[t], {t, 8}]
```




```
{12.7937, {t → 8.35395}}
```

## Productivity value and probability of success

```
ListLinePlot[{{1.28, 1.83}, {2.81, 3.78}, {6.443, 8.02}, {10.88, 12.79}},
 AxesLabel → {" Succes Probability*10^-5", "Value (m €) "}]
```