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Foreword

In order to perform a proper, integrated assessment of potential climate change impacts on Egypt it was necessary to accurately identify important and impending issues and problems which are and will be facing the Egyptian agriculture sector into the next century. To this aim, two experts in the fields of [1]Agronomy and [2]Irrigated Agriculture in the Middle East were asked to travel to Egypt in order to assess the current state of Egyptian agriculture and pose possible questions and scenarios that will face Egypt in light of its current agricultural practices and management strategies. The paper examines two possible future scenarios for Egypt, one from a non-climate change perspective and the other from a climate change outlook. These scenarios are derived from the authors perspective of the current state of Egyptian agriculture. One viewpoint is that of the pessimist, where Egypt continues to practice poor agriculture management; the other is that of the optimist, with Egypt adopting sound management practices - adapting its cropping pattern and water use practices. Also addressed are the potential impacts of climate change on crop yields and recommendations for agronomic research to mitigate its potential impact.

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EGYPTIAN AGRICULTURE IN THE 21ST CENTURY

Cynthia Rosenzweig and Daniel Hillel

INTRODUCTION

Egyptian agriculture is entirely based on irrigation and hence is utterly dependent on a tenuous balance between the supply of water (from the Nile, and to a lesser degree from groundwater) and the demand for it by crops. That balance is mainly dictated by the climate, inasmuch as climate determines both the supply of water by the Nile and the evapotranspirational demand for water imposed by atmosphere. The water balance is affected secondarily by the pattern of water use (i.e., the specific crops grown and the mode of irrigation), as well as by soil conditions and water quality (both of which appear to be deteriorating).

Any attempt to assess the future of Egyptian agriculture must consider the complex interactions of those factors, as well as the inexorable growth of population (now increasing at the rate of 2.3 percent per year) and urban encroachment (currently estimated at 10,000 to 20,000 hectares per year). The future is thus hard to project even assuming the continuation of current climate conditions, which are subject to fluctuations but not to long-term change. The task is made all the more difficult by the possibility of a significant warming trend expected to result from the enhanced greenhouse effect (IPCC, 1990; 1992).

SCENARIOS OF THE FUTURE

Recognizing that in the future, even more than in the present, the primary constraints in Egyptian agriculture will be water and land, we present herewith a number of alternative scenarios (hypothetical cases) regarding the availability, quality, and use of water, and regarding soil fertility, salinity, and drainage. We then briefly describe the present cropping systems in Egypt, discuss methods for projecting crop yields under climate change conditions, and offer definitions of some concepts critical to projecting the future of Egyptian agriculture.

Scenario 1: The Future Without Climate Change

Suppose, hypothetically, that Egypt experiences no essential change of climate in the coming decades. We can then compare and contrast two extreme visions of the future: a pessimistic "worst-case" scenario in which environmental degradation proceeds unchecked versus an optimistic "best-case" scenario of wise management of Egypt's rich natural resources.

Pessimistic Case: No Change in Crop Patterns or Water Use

A continuation of current trends in Egypt will lead to an intensifying loss of agricultural land to waterlogging and salinization, as well as to urbanization. Field water application efficiency values (defined as the fraction of the water applied that is actually used, or transpired, by the crop) in Egypt are typically well below 50 percent, and in many cases are below 30 percent. Such low values imply that more than half (and often two-thirds) of the water applied in the field exceeds the irrigation requirement of the crop.

Excess irrigation will lead to reduced crop yields below potential insofar as it impedes aeration, leaches nutrients, and induces water-table rise, salinization, and the need for expensive drainage. Concurrently, irrigation water quality will deteriorate, altogether resulting in a decrease in agricultural productivity. Average crop yields will diminish, notwithstanding the expectable improvements of varieties, fertilization, and pest control.

Especially vulnerable to the progressive degradation of land and water resources are the ill-drained areas of the lower Nile Delta that are already subject to land subsidence, water-table rise, and saline-water intrusion. Combatting these processes will require large investments in expensive drainage, and greater government intervention and regulation; if investments, interventions, and regulations are lacking or are haphazardly implemented, these lands will certainly become unusable for agriculture. The strains to the coastal and delta system may also lead to clashes among competing interests, e.g., among agricultural, urban, and industrial sectors.

Optimistic Case: Improvement of Water Use Efficiency and Crop Management

There is an opportunity and a challenge for Egypt to conserve water and reduce drainage requirements while raising crop yields in both the Old and New Lands (see Clarifications section). This is the essence of the optimistic vision of Egypt's agricultural future. Although yields in the fertile lands of the Nile Valley and Delta are already high, there is certainly room for improvement in water use efficiency. The potential increase in productivity inherent in the improvement of irrigation in the Old Lands probably exceeds the potential production increase from the reclamation of New Lands in desert areas outside the Nile Valley and Delta. The latter undertaking is not to be precluded, however, and in fact will be enhanced by water conservation in the Old Lands.

The experience of Israel is instructive, particularly in regard to the development of New Lands. In the last forty years, the average seasonal irrigation applied to field and orchard crops has been reduced by nearly 50 percent, from more than 10,000 to little over 5,000 cubic meters per hectare. At the same time, in large measure as a result of the more precise optimization of soil moisture and nutrients (as well as the improvement of crop varieties and microclimate control), average crop yields have approximately doubled. The irrigated crop productivity ratio (defined as the yield (kg) obtained per unit volume of water applied (m^3) has tripled (Figure 1).

The means necessary to achieve the potential improvement in water use efficiency are not easy to undertake and implement. Needed is a strong system of rewards and penalties to create incentives for water conservation and the installation of modern irrigation technology. Water metering and water pricing must be instituted, water must be made available on demand or at high frequency (rather on a fixed schedule at infrequent intervals), and credit as well as training should be offered to farmers willing to modernize their irrigation. In addition, efforts should be made to promote the preferential adoption of high-return, specialized and water-conserving crops instead of the presently grown water-profligate crops such as rice and sugarcane. Given Egypt's already high yields, perhaps water use efficiency values will not be quadrupled, but they can very probably be doubled.

Given a willingness to modify irrigated agriculture, to conserve water and maintain water quality, and to substitute high-return specialized crops for the subsistence grain and fodder crops now predominating, we foresee at least a doubling of agricultural production within the next fifty years or so.

Scenario 2: The Future with Climatic Warming

Herein we assume that Egypt will experience a significant rise of mean temperature in the coming century. Prediction of hydrological changes is more uncertain and solar radiation changes are projected to be small (see Table 1 for seasonal temperature, precipitation, and solar radiation changes projected for doubled atmospheric CO_2 by three global climate models (GCMs)). If no timely measures are taken to adapt Egyptian agriculture to such a warming, the effects may be negative and serious. Egypt appears to be particularly vulnerable to climate change, because of its dependence on the Nile River as the primary water source, its large traditional agricultural base, and its long coastline, already undergoing both intensifying development and erosion. If appropriate measures are taken, negative effects on these major resource sectors may be obviated or lessened. So, once again we contrast a worst-case versus a best-case scenario.

Pessimistic Case: No Adaptation to Climate Change

The expectable impact of climate change on the supply of water (i.e., on the flow of the Nile) is greatly uncertain (Strzepek et al., 1994). On the other hand, we may be certain that a warmer climate will impose a greater evaporational demand and hence will increase irrigation water requirements. This effect may be mitigated in part by the higher water use efficiency of some crops in a CO_2-enriched atmosphere (Rosenzweig and Hillel, 1993). Higher evaporation rates will have the secondary effect of worsening the tendency toward soil salinization, by speeding the transport of damaging salts to the soil surface.

In the traditional regime of infrequent irrigation common in Egypt, sensitive crops are therefore likely to suffer from increased moisture stress and salt stress. Yields may suffer additionally from the hastened maturation in a warmer climate and greater infestations of pests (Rosenzweig and Hillel, 1993). Heat-sensitive crops that are already near the limit of their heat tolerance will be especially vulnerable.

Equally serious is the potential effect of sea-level rise resulting from the thermal expansion of seawater and the melting of land-based glaciers. Even a slight rise of sea-level will exacerbate the already active process of coastal erosion along the shores of the Delta (currently 50 m per year at the head of the Rosetta branch of the Nile at Rashid), a process that accelerated after the building of the Aswan High Dam. For a 1 meter sea-level rise, 12 to 15 percent of the existing agricultural land in the Delta may be lost (Nicholls and Leatherman, 1994). Sea-level rise will also accelerate the intrusion of saline water into surface bodies of water (the lagoons and lakes of the northern Delta) as well as into the underlying coastal aquifer (El-Raey, pers. com; Sestini, 1992). The rise in the base level of drainage will further increase the tendency toward waterlogging and salinization of low-lying lands, with the consequence that significant areas will become unsuitable for agriculture. At the very least, the costs of drainage will increase.

Coupled with the deleterious effects described in the pessimistic case without climate change, global warming is likely to reduce agricultural productivity in Egypt yet further. Crop modeling simulations with GCM climate change scenarios at the high end of the IPCC range (~4°C) found that maize and wheat yields declined in the Delta by as much as 30 percent and in Middle Egypt by more than 50% (Figures 2 and 3) (Eid, 1994). In view of the continuing increase of population, Egypt may suffer a worsening shortage of food and an eventual crisis. This is indeed a worst-case scenario.

Optimistic Case: Improved Resource Management and Effective Adaptation to Climate Change

Much can be done to mitigate the potential dire consequences of climate change, and the earlier the task is recognized and undertaken - the more likely it is to succeed. The first imperative is to improve both the technical water application efficiency and the agronomic water use efficiency. This involves nothing less than revamping the entire system of water delivery and control.

Ideally, water should be made available on demand (rather than on a fixed schedule), and be delivered in measured quantities in closed conduits subject to effective monitoring and regulation while avoiding seepage losses. While this will be difficult to achieve in the Old Lands, where traditional systems exist and traditional concepts die hard, it is certainly achievable from the outset in the New Lands.

To facilitate adoption of water conservation, the authorities should provide farmers with explicit guidance regarding optimal crop selection, irrigation, and fertilization, and should institute strong incentives to avoid excessive water use (including the oft-suggested but seldom implemented pricing of water in increasing proportion to the amount used). Modern methods of irrigation based on the high-frequency, low-volume application of water and fertilizers directly to the plants need to be adapted to the scale of operation and local practicalities of Egyptian farming. Fortunately, such systems are flexible and lend themselves readily to downsizing so as to accommodate the small-scale nature of most Egyptian farming units. Moreover, such systems can be applied successfully to sandy and even to gravelly desert soils (potential New Lands) that are not considered irrigable by the traditional surface-irrigation methods.

An additional set of measures involves the careful selection and/or breeding of heat tolerant, salinity tolerant, water conserving crops; as well as controlled-environment production methods that minimize water use while maximizing the production of high-value crops (e.g., all-season vegetables and fruits, spices, medicinals).

A further set of mitigation measures involves the management of the low-lying lands on the northern fringe of the Delta, where the consequences of sea-level rise (submergence and salinization) are certain to wreak their greatest damage. Some of those lands must be retired from agriculture, and the amount of water made available consequently should be diverted to the irrigation of New Lands outside the Nile Valley and the Delta.

The overall effect of the measures listed herewith, in light of the future either with and without climate change, will be to raise the potential and actual productivity of Egyptian agriculture. Thus, climate change may not thwart progress toward the goal of providing sufficiently for the Egyptian people. A final caveat, however, is that much depends on whether the rate of population growth in Egypt, which has already begun to decline, continues to do so fast enough to allow agricultural productivity to keep pace with the country's growing needs.

CLARIFICATIONS

Here we offer explication of several key concepts and definitions used in the text regarding the present and future practices of Egyptian water use and agricultural management. These include concepts of water use efficiency, definitions of "Old Lands" and "New Lands" (key terms in Egyptian agricultural land use and development), and an assessment of land vulnerability to sea-level rise in the Nile Delta.

Concepts of Efficiency

Distinctions must be made among alternative types of efficiency in the management of irrigation. Three efficiencies may be defined: field water application efficiency, system water application efficiency, and agronomic water use efficiency.

Field water application efficiency (FWAE) is the fraction of the water applied that is consumed by the crop in transpiration in a given field. In practice, local FWAE values cannot attain 100 percent, nor should that be the aim, since a certain fraction of the water applied must be allowed to seep away and leach the salts that would otherwise accumulate in the root zone. However, with careful management FWAE values of 90 percent are possible, and of 80 percent are practicable. At present, typical values of FWAE in Egypt are considerably below 50 percent, and in many places are even below 30 percent.

System water application efficiency (SWAE) is the fraction of the volume of water taken from the source (generally, the river) that is used consumptively by crops along the entire irrigation district or region. In Egypt, especially, SWAE tends to be much greater than the local FWAE, for although it includes additional losses in conveyance (generally in open, unlined canals), it is enhanced by the repeated use in successive downstream sites of water drained from upstream sites. For the entire Nile Valley irrigation system, therefore, SWAE may be as high as 70 percent. However, this seemingly high value of "efficiency" has its drawbacks. With each successive use, the water reused undergoes degradation in energy and quality; i.e., it loses elevation and becomes progressively salinized. Hence the entire system stands to gain from efforts to improve the local FWAE.

An entirely different concept is the agronomic water use efficiency (AWUE), defined as the economic yield obtained per unit volume of irrigation applied. As such, AWUE is a truer measure of the productivity of irrigated agriculture. It is not expressed in percentage terms but in weight of produce per unit volume of water. Because of excessive irrigation, poor drainage, salinization, and nonoptimal management (e.g., insufficient or inappropriate fertilization, or poor pest control, or poor choice of crop or poor germination, etc.), AWUE may be much below the potential productivity.

Old Lands and New Lands

In our usage, Old Lands refer to lands along the Nile Valley and in the Delta that are irrigated directly from the Nile or from groundwater fed by the Nile. By and large, these lands have been under irrigation for long periods of time. The predominant soils here are alluvial silt and clay loams. In contrast, New Lands refer to desert areas outside the Nile Valley, to which water must be conveyed over some distance from the Nile, or supplied from deep wells. The New Lands are distributed west of the Delta (Nubaria), east of the Delta (Salhia and along the western side of the Suez Canal), in the northern Sinai, and in the New Valleys of the Western Desert. The soils here are generally sandy and calcareous, not nearly as naturally fertile as the alluvial soils. However, they are often readily drainable, though often more prone to salinity.

Degraded (waterlogged and salinized) Old Lands that need to be rehabilitated are not included in the New Lands category. As these are reclaimed through drainage and leaching, they are referred to as "New-Old Lands."

Lands Most Vulnerable to Sea-level Rise

Most vulnerable to sea-level rise are the low-lying lands along the northern strip of the Delta, where the surface elevation is less than 1 meter above sea level. Owing to land subsidence (perhaps 0.1 meter in 50 years), as well as expectable sea-level rise (variously estimated to total 0.2 to 0.5 meter in the same time period), that widening strip of land may reach 20 kilometers or more. Within this strip, the maintenance of agriculture will become progressively more difficult, and eventually much land will be retired from production. Urban and industrial development, too, will be problematic because of waterlogging, and the ecology and economy of the lagoons will be affected by saline water intrusion. Drainage to control waterlogging will become increasingly expensive.

CURRENT CROPPING SYSTEMS

Egypt's warm mean annual temperature, high solar radiation receipts, fertile soils, and abundant water supplies from the Nile River have created a rich agricultural system that has been in place for approximately 5000 years. The Old Lands of the Nile Delta and river-fed Middle and Upper Egypt have been continuously farmed throughout this period. In the last twenty years, the Egyptian government has promoted expansion of agriculture into New Lands located in desert regions, and the reclamation of long-used areas now salinized or water-logged called New-Old Lands.

In the Nile Delta and along its banks, agriculture is characterized by complex year-long cropping patterns carried out by traditional farmers on small units of land with complicated land-tenure relationships. Two-thirds of the landowners in Egypt own less than 5 feddans (one feddan equals 0.4 hectare) (Table 2) (CAPMAS, 1993). Agriculture in the Old lands is so intensively managed that it may be better represented by the term "gardening" rather than "farming."

Three cropping periods are utilized per year. Winter crops are sown in October and November; summer crops are sown in April and May; and Nilé (or Kharif) crops are sown in July and August. Perennial crops, such as sugar cane and alfalfa, are sown either in the spring (March) or in the autumn (October). Cotton is a relatively long duration summer crop and is planted in March. Vegetables are planted all year long, with spring and autumn plantings added to summer and winter plantings. In the New Lands, major crops are primarily fruit and oil trees, and vegetables, planted in larger fields. Intensive management of modern irrigation is needed to sustain these crops at high productive levels. Twenty-eight major seasonal crops may be identified in the current cropping system (Table 3).

PROJECTING CROP YIELD CHANGES

A task at hand for climate change studies is to estimate the potential impacts on yield and water use for the crops listed in Table 3. Crop models are now available for most of the major crop grown in Egypt to accomplish this task (Table 4). Dynamic process crop simulation models are recommended so that changes in agronomic processes, such as water stress, crop phenology, and crop failure, may be studied in detail. Crop models are also useful for testing potential adaptations to climate change such as changes in planting dates and shifts in cultivars or crops (Rosenzweig and Parry, 1994).

The simulation of climate change effects on agricultural production in Egypt requires a coordinated effort in which data, computer software, and expertise from various disciplines and institutions are integrated. The first step is to calibrate and validate the models with local agronomic experimental data for a set of sites representative of major Egyptian agricultural regions (e.g., Eid, 1994). Next, simulations with observed climate provide a baseline. Then, the crop model simulations are run with a suite of climate change scenarios. Examples of crop simulations for two sites in Egypt are shown in Figures 2 and 3.

CONCLUSION

While Egypt's future is likely to be neither as dire as our pessimistic scenarios or as bright as our optimistic ones, it is clear that the country's vulnerability to climate change is acute. Rapid increases in population and urbanization will only exacerbate this vulnerability. Given the intertwined linkages of the Nile River, its Delta, the coastal resources, and the surrounding deserts, potential impacts of climate change must be addressed in an integrated mode by joining the disciplines of hydrology, agronomy, and coastal zone geography. By so doing, progress will be made in understanding critical environmental processes, thus improving the future for the Egyptian people, whatever it holds.

REFERENCES

CAPMAS. 1993. *Statistical Year Book: Arab Republic of Egypt 1952-1992*. Central Agency for Public Mobilization and Statistics. Cairo.

Eid, H.M. 1994. Impact of climate change on simulated wheat and maize yields in Egypt. In C. Rosenzweig and A. Iglesias (eds). *Implications of Climate Change for International Agriculture: Crop Modeling Study*. U.S. Environmental Protection Agency. Washington, DC (in press).

IPCC. 1990. *Climate Change: The IPCC Scientific Assessment*. H.T. Houghton, G.J. Jenkins, and J.J. Ephraums (eds). Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge.

IPCC. 1992. *Climate Change 1992*. The Supplementary Report to the IPCC Scientific Assessment. J.T. Houghton, B.A. Callander, and S.K. Varney (eds). Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge.

Nicholls, R.J. and S.P. Leatherman. 1994. Sea-Level Rise. In Strzepek, K.M. and J.B. Smith (eds). *As Climate Changes: International Impacts and Implications*. Cambridge University Press. Cambridge (in press).

Rosenzweig, C. and D. Hillel. 1993. Agriculture in a Greenhouse World: Potential Consequences of Climate Change. *National Geographic Research and Exploration 9(2):208-221.*

Rosenzweig, C. and M.L. Parry. 1994. Potential impacts of climate change on world food supply. *Nature* 367:133-138.

Sestini, G. 1992. Implications of climatic changes for the Nile Delta. In L. Jeftic, J.D. Milliman, and G. Sestini. 1992. *Climatic Change and the Mediterranean*. Edward Arnold. London. pp. 535-601.

Strzepek, K.M., D.N. Yates, S.C. Onyeji, and M. Saleh. 1994. A socio-economic analysis of integrated climate change impact on Egypt. In Strzepek, K.M. and J.B. Smith (eds). *As Climate Changes: International Impacts and Implications*. Cambridge University Press. Cambridge (in press).

CROP MODEL REFERENCES

Acock, B. V.R., Reddy, F.D. Whisler, D.N. Baker, J.M. McKinion, H.F. Hodges and K.J. Boote. 1983. The soybean crop simulator GLYCIM: Model Documentation 1982. Report No. 2, U.S. Dept. of Energy, Carbon Dioxide Research Division, Office of Energy Research, Washington, DC.

Aggarwal, P.K. and F.W.T. Penning de Vries. 1989. Potential and water-limited yields in rice-based cropping systems in Southeast Asia. *Agr. Systems* 30: 49-69.

Arkin, G.F., R.L. Vanderlip and J.T. Ritchie. 1976. A dynamic grain sorghum growth model. *Transactions of the ASAE* 19(4): 622-626, 630.

Baker, C.H. and R.D. Horrocks. 1976. CORNMOD, A dynamic simulator of corn production. *Agric. Systems* 4:57-77.

Baker, D.N., J.R. Lambert and J.M. McKinion. 1983. GOSSYM: A simulation of cotton crop growth and yield. Tech Bull. 1089. South Carolina Agric. Exp. Station, Clemson. 134 pp.

Boote K.J., J.W. Jones, J.W. Mishoe, and G.G. Wilkerson. 1985. Modeling growth and yield of groundnut. In Proceedings of the Int'l Symposium on Agrometeorology of Groundnut. ICRISAT, Sahelian Center, Niamey, Niger. 32pp.

Brown, L.G., J.W. Jones, J.D. Hesketh, J.D. Hartsog, F.D. Whisler and F.A. Harris. 1985. COTCROP: Computer simulation of growth and yield. Information Bull. No. 69. Miss. Agr. and Forestry Exp. Station, Miss. State, MS.

Buttler, I.W. 1989. Predicting water constraints to productivity of corn using plant-environmental simulation models. Ph.D. diss., Cornell Univ., Ithaca, NY.

Childs, S.W., J.R. Giley and W.E. Splinter. 1977. A simplified model of corn growth under moisture stress. *Transactions of the ASAE* 20(5): 858-865.

Curry, R.B., C.H. Baker and J.G. Streeter. 1975. SOYMOD I: A dynamic simulator of soybean growth and development. Transactions of the ASAE 18(5): 963-968.

Dennison, R.F. and R.S. Loomis. 1989. An integrative physiological model of alfalfa growth and development. (complete citation unavailable).

Duncan, W.G. 1975. SIMAIZ: A model simulating growth and yield in corn. In An application system method to crop production , eds. D.N. Baker, P.B. Creech and F.G. Maxwell, 34-48. Mississippi Agric. Forestry Exp. Stn., State College, MS.

Fick, G.W. 1981. ALSIM I (Level 2) User's manual. Agron. Mimeo 81-35, Dept. of Agron., Cornell Univ., Ithaca, NY. 14853.

Godwin, D.C., J.T. Ritchie, U.Singh and L.Hunt. 1990 A user's guide to CERES-Rice - V2.10. Inter. Fert. Devel. Center. P.O. Box 2040, Muscle Shoals, AL. 86 pp.

Godwin, D.C., and P.L.G. Vlek. 1985. Simulation of nitrogen dynamics in wheat cropping systems. In Wheat Growth and Modeling, eds. W. Day and R.K. Arkin. New York: Plenum Press.

Hodges, T., B.S. Johnson and L.A.Manrique. 1989. SUBSTOR: A model of potato growth and development. In *Agronomy Abstracts*, 16. Madison, WI: ASA.

Hoogenboom, G., J.W. White and J.W.Jones. 1989. A computer model for the simulation of bean growth and development. In *Advances in Bean (Phaseolus vulgaris L.) Research and Production*. CIAT Publication No. 23, Cali, Columbia.

Horie, T. 1988. Simulated rice yield under changing climatic conditions in Hokkado Island. In. *Assessment of Climate Effects on Agriculture*, Vol I, eds. M.L. Parry, T.R. Carter and N.T. Konijn. Dordrecht: Kluwer Academic Publishers.

Inman-Bamber, N.G. 1991. A growth model for sugar-cane based on a simple carbon balance and the CERES-Maize water balance. *South African Journal of Plant Science* 8(2): 93-99.

Jackson, B.S., G.F. Arkin and A.B. Hearn. 1988. The cotton simulation model "COTTAM": Fruiting model calibration and testing. *Transactions of the ASAE* 31(3): 846-854.

Jones, C.A. and Kiniry, eds. 1986. *Ceres-Maize: A Simulation Model of Maize Growth and Development*. College Station: Texas A&M University Press.

Jones, J.W., K.J. Boote, S.S. Jagtap, G. Hoogenboom and G.G. Wilkerson. 1989. SOYGRO v5.42 Soybean crop growth simulation model. User's guide. Florida Agr. Exp. Station Journal No. 8304. University of Florida, Gainesville.

Jones, J.W. and J.R. Ritchie. 1990. Crop Growth Models. In Management of Farm Irrigation Systems, Ch 4, eds. Hoffman, G.J., T.A. Howell and K.H. Soloman. Amer. Soc. of Agr. Eng. Monograph, St. Joseph, MI.

Maas, S.J. and G.F. Arkin. 1980a. TAMW: A wheat growth and development simulation model. Research Center Program and Model Development No. 80-3, Texas Agric. Exp. Stn. Blackland Research Center, Temple TX.

Monteith, J.L., A.K.S. Huda and D. Midya. 1989. RESCAP: A resource capture model for sorghum and pearl millet. In *Modeling the growth and development of sorghum and pearl millet*, eds. S.M. Virmani, H.L.S.Tandon and G. Alagarswamy. 30-34. Research Bulletin No.12. ICRISAT. Andhra Pradesh, India.

Morgan, T.H., A.W. Biere and E.T. Kanemasu. 1980. A dynamic model of corn yield response to water. *Water Resour. Res.* 16(10):59-64.

Newkirk, K.M., J.C. Parker, J.C. Baker, E.W. Carson, T.B Brumback, Jr. and O. Balci. 1989. User guide to VT-Maize Version 1.0 (R). Virginia Water Resources Res. Ctr., Virginia Polytechnic Inst. and State Univ., Blacksburg, VA.

Ng, E. and R.S. Loomis. 1984. *Simulation of Growth and Yield of the Potato Crop*. PUDOC, Wageningen.

Norman, J.M. and G. Campbell. 1983. Application of a plant-environment model to problems on irrigation. *Adv. Irrig.* 2:155-188.

Ritchie, J.T. 1985. A user-oriented model of the soil water balance in wheat. In *Wheat Growth and Modeling*, eds. W. Day and R.K. Arkin. New York: Plenum Press.

Ritchie, J.T., and G. Alagarswamy. 1989. Simulation of sorghum and pearl millet phenology. In *Modeling the growth and development of sorghum and pearl millet*, eds. S.M. Virmani, H.L.S.Tandon and G. Alagarswamy. 24-26. Research Bulletin No.12. ICRISAT. Andhra Pradesh, India.

Ritchie, J.T., B.S. Johnson, S. Otter-Nacke and D.G. Godwin. 1989. Development of a barley yield simulation model. Final progress report. USDA No. 86-CRSR-2-2867. Michigan State Univ., East Lansing, MI.

Ritchie, J.T., U.Singh, D.C. Godwin and L.Hunt. 1989 A user's guide to CERES-Maize - V2.10. Inter. Fert. Devel. Center. P.O. Box 2040, Muscle Shoals, AL. 86 pp.

Rosenthal, W.D., R.L. Vanderlip, B.S. Jackson and G.F. Arkin. 1989. SORKAM: A grain sorghum crop growth model. MP 1669. Texas A. Expt. Sta., College Station. 205 p.

Stapper, M. 1984. SIMTAG: A simulation model of wheat genotypes. pp.108. University of New England, Dept. Agron. and Soil Sci. Armidale, NSW, Australia.

Stapper, M. and G.F. Arkin. 1980. CORNF: A dynamic growth and development model for maize (Zea mays L.) Program and documentation No. 80-2. Texas Ag. Expt. Sta., College Station. 91 p.

Stockle, C.O. and G.S. Campbell. 1989. Simulation of crop response to water and nitrogen: An example using wheat. *Transactions of the ASAE* 32(1): 66-74.

van Keulen, H. and N.G. Seligman. 1987. Simulation of water use, nitrogen nutrition, and growth of a spring wheat crop. Centre for Ag. Publ. and Doc. Wageningen, The Netherlands.

Wilkerson, G.G., J.W. Jones, K.J. Boote, K.T. Ingram and J.W. Mishoe. 1983. Modeling soybean growth for crop management. *Transactions of the ASAE* 26(1): 63-73.

Williams, J.R., C.A. Jones and P.T. Dyke. 1984. A modeling approach to determining the relationship between erosion and soil productivity. *Transactions of the ASAE* 27(1): 129-144.

Young, J.H., F.R. Cox and C.K. Martin. 1979. A peanut and development model. *Peanut Sci*. 6:27-36.

Table 1. GCM climate change scenarios for Egypt.

GCM CLIMATE CHANGES AT SAKHA AND GIZA

Temperature Change (°C)

	GISS	GFDL	UKMO
Spring	5.1	4.5	4.7
Summer	3.2	4.4	4.1
Autumn	4.4	4.1	4.5
Winter	4.0	3.7	4.5
Annual	4.2	4.2	4.4

Precipitation Change (%)

	GISS	GFDL	UKMO
Spring	-7.1	-19.2	-12.5
Summer	350.0	0.0	-37.0
Autumn	27.3	-20.0	1.2
Winter	5.9	-10.0	-8.9
Annual	55.7	-15.3	-13.8

Solar Radiation Change (%)

	GISS	GFDL	UKMO
Spring	-0.3	2.0	6.2
Summer	-4.2	-0.6	6.1
Autumn	-1.2	0.6	1.3
Winter	0.0	0.8	8.7
Annual	1.7	0.6	5.5

GISS, Goddard Institute for Space Studies
GFDL, Geophysical Fluid Dynamics Laboratory
UKMO, United Kingdom Meteorological Office

Table 2. Ownership of land, by number of feddan, and percent of total landowners (CAPMAS, 1993).

Ownership (feddan)	Landowners (percent)
less than 1	12.6
1-3	34.4
3-5	20.1
5-10	16.0
10-50	16.7
>50	0.2

1 feddan = 0.4 hectare

Table 3. Current crops and cropping pattern in Egypt.

Season	Crop	Season	Crop
Long	Berseem	Summer	Maize
Short	Berseem	Summer	Sorghum
	Wheat		Soybeans
	Barley		Groundnut
	Horse-bean		Sesame
	Lentils	Summer	Potato
	Other legumes	Summer	Tomato
	Flax	Summer	Vegetables
Winter	Onion	Nile	Maize
Winter	Tomato	Nile	Sorghum
Winter	Vegetables	Nile	Potato
	Seed cotton	Nile	Tomato
	Rice	Nile	Vegetables
	Citrus		Sugarcane

Long = 4-5 cuts
Short = 2 cuts

Nile = sown in July or August

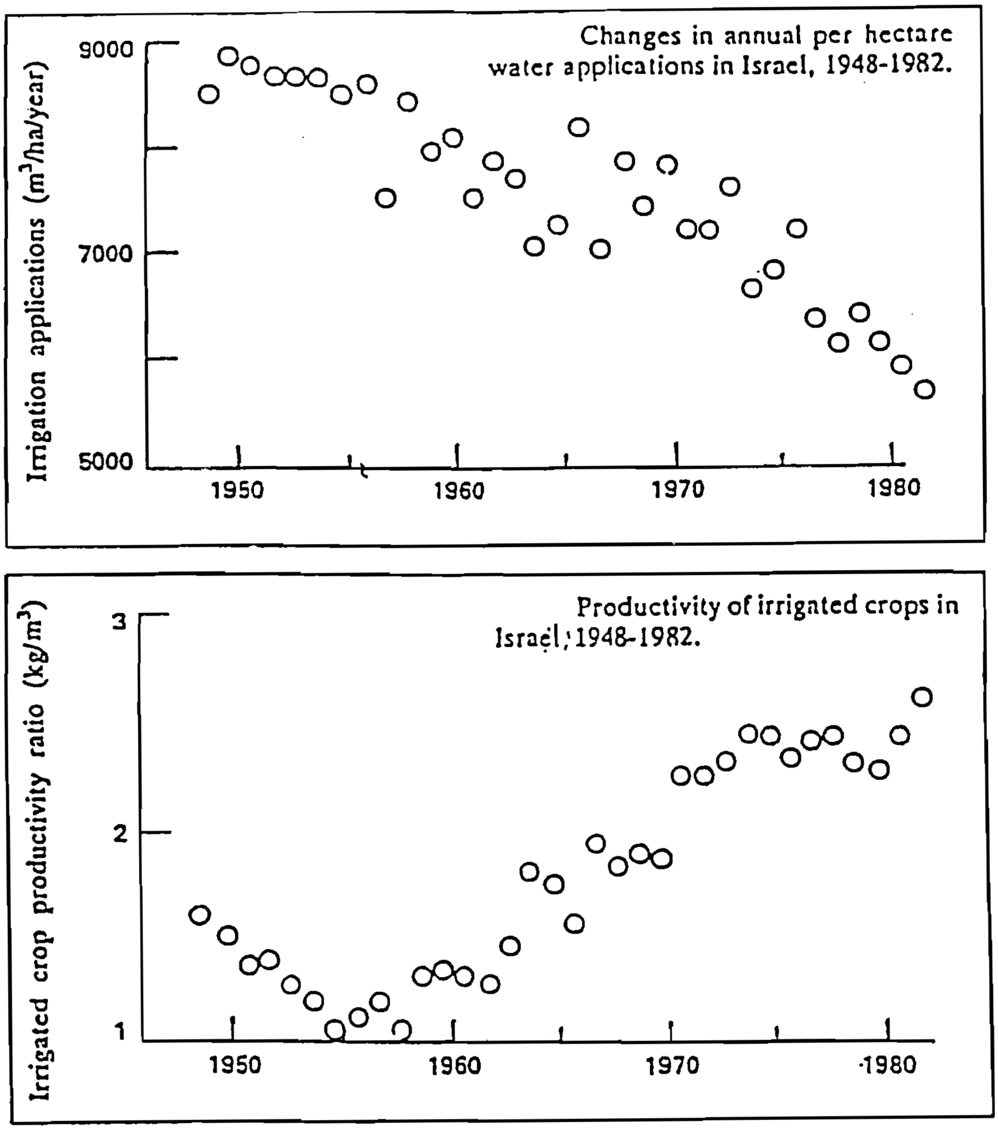
Table 4. Selected dynamic process crop growth models.

Crop	Model Name	Reference
Alfalfa	ALSIM (Level 2)	Fick (1981)
	ALFALFA	Dennison and Loomis (1989)
Barley	CERES-Barley	Ritchie et al. (1989)
Cotton	GOSSYM	Baker et al. (1983)
	COTCROP	Brown et al. (1985)
	COTTAM	Jackson et al. (1988)
Dry Bean	BEANGRO	Hoogenboom et al. (1989)
Maize	CERES-Maize	Jones and Kiniry (1986); Ritchie et al. (1989)
	(unnamed)	Stockle and Campbell (1985)
	CORNF	Stapper and Arkin (1980)
	SIMAIZ	Duncan (1975)
	CORNGRO	Childs et al. (1977)
	CORNMOD	Baker and Horrocks (1976)
	(unnamed)	Morgan et al. (1980)
	VT-Maize	Newkirk et al. (1989)
	GAPS	Buttler (1989)
	CUPID	Norman and Campbell (1983)
Peanut	PNUTGRO	Boote et al. (1989)
	(unnamed)	Young et al. (1979)
	RESCAP	Monteith et al. (1989)
Potato	(unnamed)	Ng and Loomis (1984)
	SUBSTOR	Hodges et al. (1989)
Rice	CERES-Rice	Godwin et al. (1990)
	RICEMOD	McMennamy and O'Toole (1983)
	(unnamed)	Horie (1988)
Sorghum	SORGF	Arkin et al. (1976)
	CERES-Sorghum	Ritchie and Alagarswamy (1989)
	SORKAM	Rosenthal et al. (1989)
	RESCAP	Monteith et al. (1989)

Table 4. Cont.

Soybean	SOYGRO	Wilkerson et al. (1983); Jones et al. (1989)
	GLYCIM	Acock et al. (1983)
	REALSOY	Meyer (1985)
	SOYMOD	Curry et al (1975)
Sugar-cane	CANEMOD	Inman-Bamber (1991)
Wheat	CERES-Wheat	Ritchie (1985); Godwin and Vlek (1985)
	(unnamed)	Stockle and Campbell (1989)
	TAMW	Maas and Arkin (1980)
	(unnamed)	Aggarwal and Penning de Vries (1989)
	(unnamed)	van Keulan and Seligman (1987)
	SIMTAG	Stapper (1984)
General Model	EPIC	Williams et al. (1984)

FIGURES



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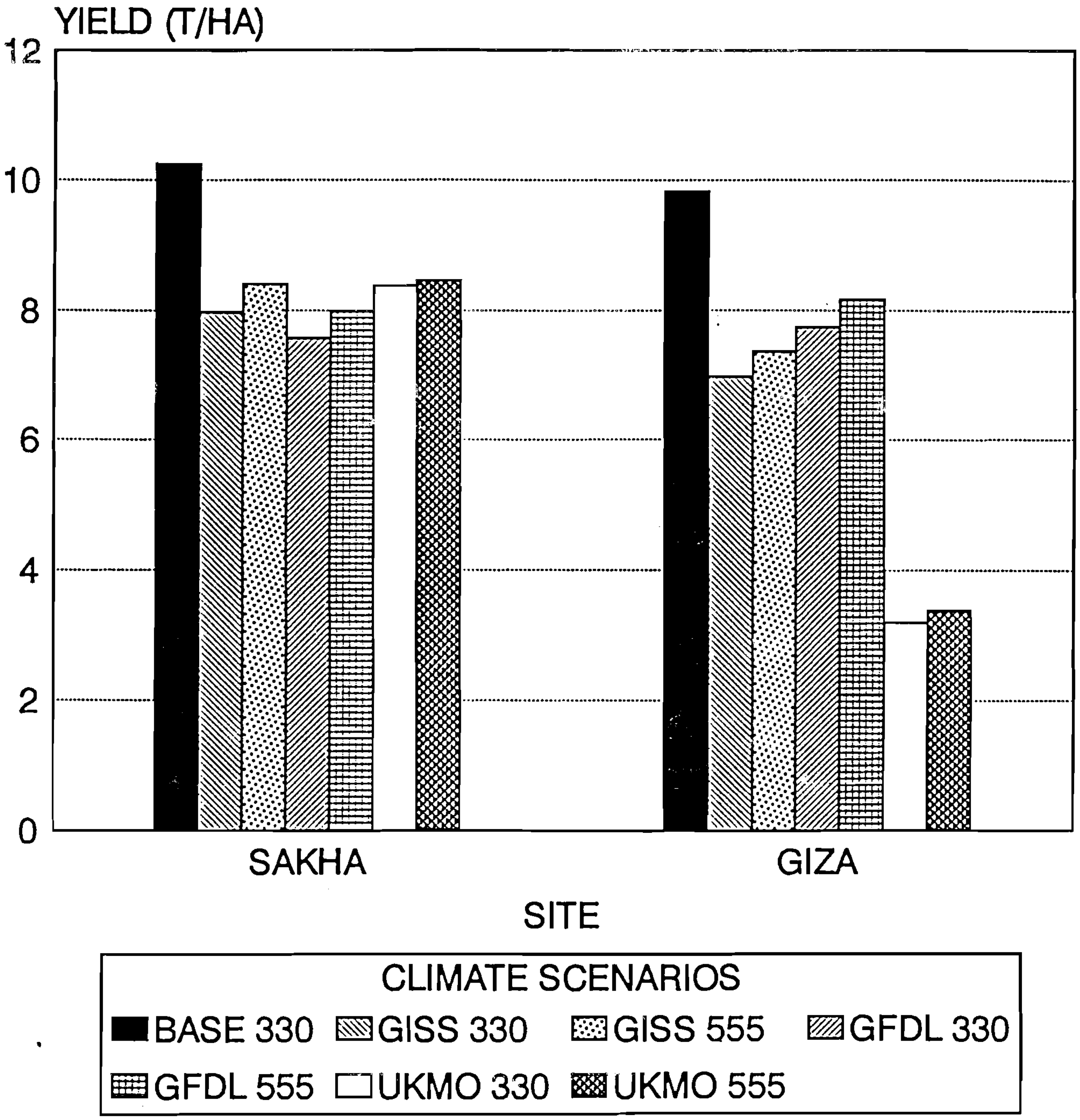
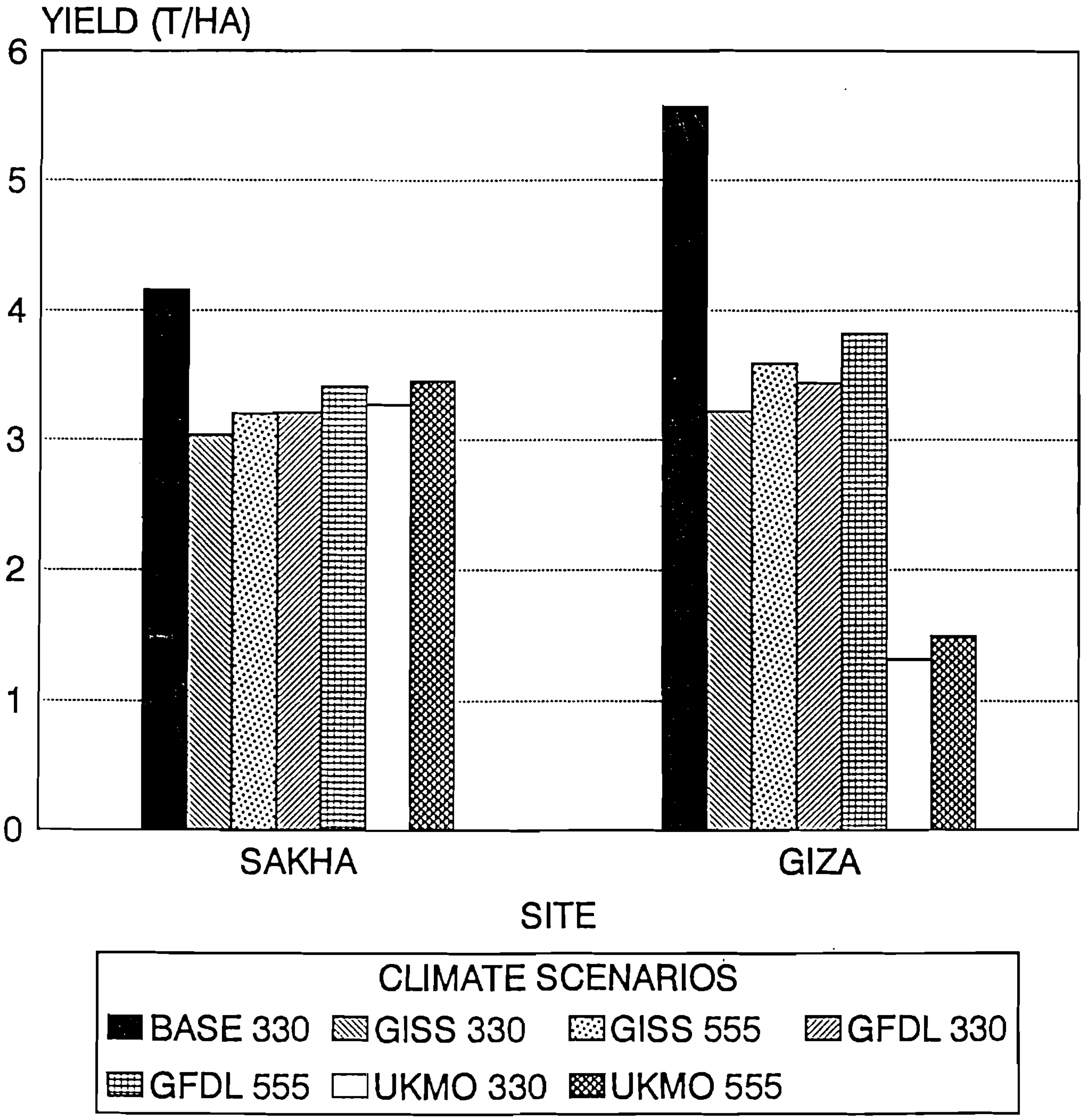
Source: H. Bielorai, Irrigation Research in the Institute of Soils and Water of the Volcanic Center - Goals and Achievements.

Figure 1.



Irrigated simulation

Figure 2.



Irrigated simulation

Figure 3.