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Uncertainties in Estimating Ecological Effects of Ozone under Egyptian Climatic Changes

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Abstract: An Ideal farm in Abbis village (Northern Egypt) was selected, with ozone (O_3) levels recorded in 1999 used as the reference scenario. Experimental dose-response functions for seven important crops were included. With the aid of linear programming model OPTICROP, the maximum difference between the proceeds of production and the variable costs was determined for different levels of O_3 by optimizing the structure of production. The economically most efficient structure was chosen from 29 possible crop rotations. The model predicts that increasing O_3 pollution causes a shift from rotation with O_3-sensitive crops (e.g. radish) to rotations with predominantly O_3-tolerant crops (e.g. barley). On acreage, an increase in O_3 level by 10% leads to a decrease in the total gross margin of 4%. Parallel to structural changes in production, the requirement for production factor (e.g. machinery, use of fertilizers, etc.) changes. It is concluded that O_3 pollution can have important economic consequences, which could affect political decision-making.

Key words: O_3-level, crop production and yield, modeling

Introduction

A preliminary risk analysis for the phytotoxic effect of air pollutants based on (I) published dose-response functions for selected crops and (ii) pollutant concentrations typical for the agricultural region of Abbis, it was concluded that ozone (O_3) was the only pollutant gas on a regional scale (Hassan, 1998; Hassan *et al.*, 1995). Ozone a typical secondary air pollutant produced photochemically from nitrogen oxides (NO_X) and volatile organic compounds (VOC), occur in concentrations high enough to affect the metabolism of sensitive species (Fig. 1).

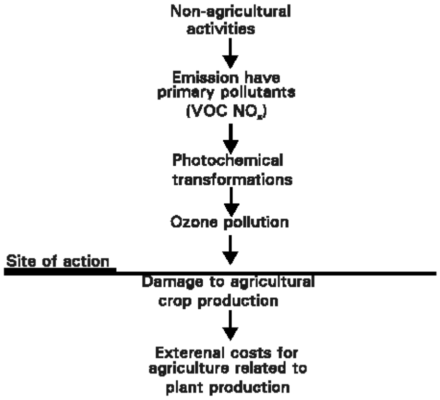

Fig. 1: Sequancial presentation of O_3 pollution

It is well recognized that economic arguments are important aspects in discussions concerning environmental politics. Money as common measure can help to overcome the problems of communication. Environmental economists address this task, but a close collaboration with natural scientists is inevitable.

This idea was fundamental to the National Crop Loss Assessment Network (NCLAN) in the States, which investigated the effect of air pollution on crops. From start of the programme, requirements by environmental economists were incorporated into the design of the scientific experiments. This closer interdisciplinary collaboration made it possible to use experimental data, in particular empirical dose-response functions for the effect of ozone on important crops, to study a range of economic questions. A considerable number of publications appeared with quantified monetary effects of different pollution scenarios on agricultural plant production in different regions, or they addressed the question of air pollution effects on the distribution of economic rents between different regions or between different producers (natural scientists) and consumers (politicians and public) of agricultural products (Adams *et al.*, 1982, 1984; Adam and Mccarl, 1985).

The aim of this study was to make a quantitative estimate of economic consequences of air pollution in case of ideal farming in Egypt. For the present investigation, crop yield was used as economically relevant parameter to estimate effects of selected O_3 exposures.

Materials and Methods

Dose-response functions for the effect of O_3 on crop yield were used for seven crop species. The functions were obtained from open-top chambers experiments as designed by Heagle *et al.* (1973) (Table 1).

Table 1: Exposure-response functions for the effect of O_3 on yield of selected crops

Crops	Function
Wheat	$Y = \exp[-(X_7/0.089)^{2.36}]$
Radish	$Y = \exp[-(X_7/0.089)^{4.3}]$
Corn	$Y = \exp[-(X_7/0.089)^{3.95}]$
Turnip	$Y = \exp[-(X_7/0.089)^{2.95}]$
Bean	$Y = \exp[-(X_7/0.089)^{1.54}]$
Potato	$Y = 1 - 3.4 X_{12}$
Barley	$Y = 1 - 1.03 X_7$

Y = Relative yield; X_7 = seasonal 7h/day mean O_3 concentrations; X_{12} = seasonal 12h/d mean O_3 concentrations

Table 2: Hypothetical O_3 scenario

	Seasonal mean O_3 concentrations (ppb)	
Scenarios	7h/day*	12h/day**
SO ambient level (reference)	41.0	40
S1 background level	20.0	20
S2 ambient level+10%	45.1	44
S3 ambient level+20%	49.2	48
S4 ambient level+30%	533.0	52
S5 ambient level+40%	574.0	56
S6 ambient level+50%	61.5	60
S7 ambient level+100%	82.0	80

* = 0900 - 1600 h; ** = 0900 - 2100h.

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By using quantitative dose-response functions to link together the biological with the economic level, it was possible to integrate the effect of O_3 on crop yield into an economic model.

To stimulate effects of different scenarios on the agricultural system selected for this case study, a programming model was used, which is commonly applied for the study of bio-economic problems (Howitt *et al.*, 1990). Taking into account a number of technical restriction to which the model system is subjected to optimizes a target function. The target function measures an economic parameter that depends on the problem to be solved. By using dose-response functions it is possible to integrate the O_3 levels as an ecological restriction into the model. Based on this procedure, statements about O_3 effects on economic variables on one hand and on optimum factor inputs and production outputs, on the other hand are possible.

Economic model and input data: The computer-aided linear programming model OPTICROP was used (Fuhrer *et al.*, 1989). The model, which optimizes crop rotation, was adjust to the question of this study, in particular by defining (a) the model region, (b) certain variables and parameters relevant for the selected type of farming and (d) the set of pro-determined crop rotations. In addition to structural adjustments of the model, the input data needed to be defined.

The model region consisted of 300 ha. On the basis of seven crops for which dose-response functions were available, a total of 29 agronomically meaningful crop rotations (CR) could be included. For the definition of model data, i.e., the definition of the prices of products and factors, the technical input-output coefficients (amount of production factor necessary for the production of one unit) and the limitation of the amount of individual factors.

The problem of optimization with the adjusted model was to assign available crop rotations to me selected acreage by taking into account a set of limitations (e.g. limited number of workers) in order to maximize the difference between the proceeds and the variable costs (= gross margin to cover me costs of me fixed factors used in crop production).

In a first step, empirical and statistical data were put into the model. By definition, the model outputs produced with these data were assigned to a particular O_3 level. This reference O_3 level was calculated as the acreage of O_3 concentrations recorded in 1999 in the area used to form the model region. Based on the dose-response functions, the actual yield and certain input coefficients could then be calculated for the different O_3 levels. Ultimately, the model could be used to determine the effect of different hypothetical O_3 scenarios on the selected agricultural system. In particular, information about (a) O_3-induced adjustments in crop production on the output side (quantity and structure of production) and on the input side (quality and structure of production factors) and (b) O_3-induced changes of the gross margin for crop production (= monetary results) could be produced.

Hypothetical O_3 scenarios: A total of seven hypothetical scenarios were defined (Table 2). S1 represented a situation with presumably only natural levels of O_3 and no anthropogenic pollution (background scenario). Scenario O_3 was the reference O_3 level (actual concentration measured in 1999) and for S2 to S6, the reference O_3 level was increased by increment 10%. S7 represented a situation with doubling of the actual O_3 level.

Results and Discussion

Reference scenario vs background scenario: At the lowest O_3 level (background scenario, scenario 1) relative to the reference level (SO), rotations with O_3-tolerant crops (CR 28) are replaced by rotations with relatively O_3-sensitive crops (CR 22). This is under the assumptions, that prices for products and subsidies for production remain constant and with business-as-usual for agricultural policy (Table 3). For example, when O_3 levels are cut in half relative to the reference scenario, crop rotations with O_3-tolerant corn are less attractive economically compared to rotations with wheat or radish. This change in the mixture of crops is accompanied by a change in the structure of production. The relative acreage of O_3-sensitive crops is at higher or at lower O_3level, with the exception of relative O_3-tolerant barley for which the acreage increased from 17 to 23%. This trends due to the fact that the model optimizes sets of crops rather than individual crop.

Several of 29 crop rotations used in the model are composed of crops with different O_3, tolerance. At the lower O_3 level, rotations with smaller portions of these tolerant crops can be favored due to an increased gross margin and consequently, acreage of tolerant crops increases. For example, winter barley gains acreage at the SO, O_3 level in spite of high tolerance, because the economically more profitable CR 22 replaces CR 28 without winter barley with winter barley covering 1/5 of the total acreage.

Effects of changes in yield and acreage act synergistically. This leads to an increase in the quantity of the crops produced under S1 that is higher than expected from the dose-response functions. The exceptions are turnip, the quantity of production of which remains constant in spite of high O_3-sensitivity. This is due to the prescribed upper limit for annual production, which is set to 241'000 t. Corn for which the dose-response function predicts the earliest response to O_3 at the actual O_3 level is eliminated under S1.

The model contains fixed technical relationships (production functions) between a unit of production (t ha^{-1}) and the necessary quantity of production factors. Therefore, any change in the quantity of production leads to a change in the quantity of production factors. For instance, the replacement of O_3 tolerant corn, which is a labor-extensive crop by labor-intensive but O_3-sensitive crops like potatoes and radish, leads to an increase in the use of manpower. Alternatively, the costs for machinery are reduced when crops that require 30 to 40 % less machinery for production replace corn. At the lower O_3-level, costs for seeds are higher, while the costs for auxiliary materials (pesticides, commercial fertilizers) are increased in some cases and decreased in others.

With respect to monetary effect of reducing the O_3 level from the reference level to the background level, the model predicts an increase in the gross margin for crop production of 550.00 L.E. per hectare. For the entire model region, this amounts to an additional 165.000 L.E., which would be available to cover fixed factors and build up capital resources.

Reference scenario vs hypothetically increased O_3 scenarios: The model predictions for S2 to S7 with increased O_3 pollution are partly opposite to those for S1. With increasing O_3, crop rotations with predominantly O_3-sensitive crops are replaced by rotations with O_3-tolerant crops. No decrease in the total acreage of farmland occurs, but productivity per unit area declines with increasing O_3. At the extreme (S7), the gross margin drops to only 60% of the value under reference scenario. Up to S5, the changes in crop rotation with increasing O_3 lead to the replacement of rotations by rotations dominated by feed grains (corn and Barley) (Table 4). At higher levels of O_3 (S6, S7), the optimum combination of rotations remains unchanged, but crop rotations of turnip and potatoes are favored in the distribution of acreage over rotations with only cereals. This seems to be a contradiction because potatoes are more sensitive to O_3 than feed grains. Again, this effect is caused the fact that sets of crops rather than individual crops are optimized by the model.

The changes in crop rotation are similar to the shifts in the structure of production (Table 5). The most striking effect of increasing O_3 is the massive decline in the acreage of feeding crops.

Changes in the quantity of production reflect the combined effect of O_3 on both acreage and yield of individual crops. Importantly, the changes predicted by the model for elevated O_3 levels differ

Table 3: Changes in crop rotation for scenario (S1 = background level) relative to the reference level (S0 = ambient level)

	Acreage (ha)		Change in	
Crop rotation	SO	S1	(ha)	(%)
Rotation CR 18 (KA, W W, WG, KW)	152.0	171.0	+19.0	+12.5
Rotation CR 21 (ZR, W W, WG, KW)	60.0	55.0	-5.0	-8.3
Rotation CR 28 (KM, KM, W W, KW,KW, KW)	88.0	0.0	-88.0	-100.0
Rotation CR 22 (W W, WG, KW, KW, KW)	0.0	74.0	+74.0	+100.0

Table 4: Changes in crop rotation with increasing ozone

	Acreage (ha)						
Crop rotation	SO	S2	S3	S4	S5	S6	S7
Rotation CR 18 (KA, WW, WG, KW)	152	141	101	0	0	0	0
Rotation CR 21 (ZR, WW, WG, KW)	60	0	0	0	0	0	0
Rotation CR 28 (KMKM, WW, KW, KW,KW)	88	90	0	0	0	0	0
Rotation CR 19 (ZR, WW, WG, KM)	0	69	70	73	75	79	94
Rotation CR 15 (KA, WW, WG, KM)	0	0	115	121	108	118	123
Rotation CR 26 (KM, WW, G,KW,KW,KW)	0	0	14	106	0	0	0
Rotation CR 1 (KM, WW, SG. WW, WG)	0	0	0	0	117	103	83
Total	300	300	300	300	300	300	300

Table 5: Changes in structure of production with increasing O_3

	Acreage (ha)						
Crops	SO	S2	S3	S4	S5	S6	S7
WW	65	64	60	61	93	90	86
WG	55	53	60	61	64	65	69
SG	00	00	00	00	17	21	09
KM	31	41	58	61	64	65	69
KA	38	33	34	32	29	31	35
ZR	15	17	16	18	33	28	32
KW	96	140	72	67	0	0	0
Total	300	300	300	300	300	300	300

W W = Wheat; WG = Winter barley; SG = Spring barley; KM = Corn; KA = Potatoes; ZR = Turnip; KW = Radish

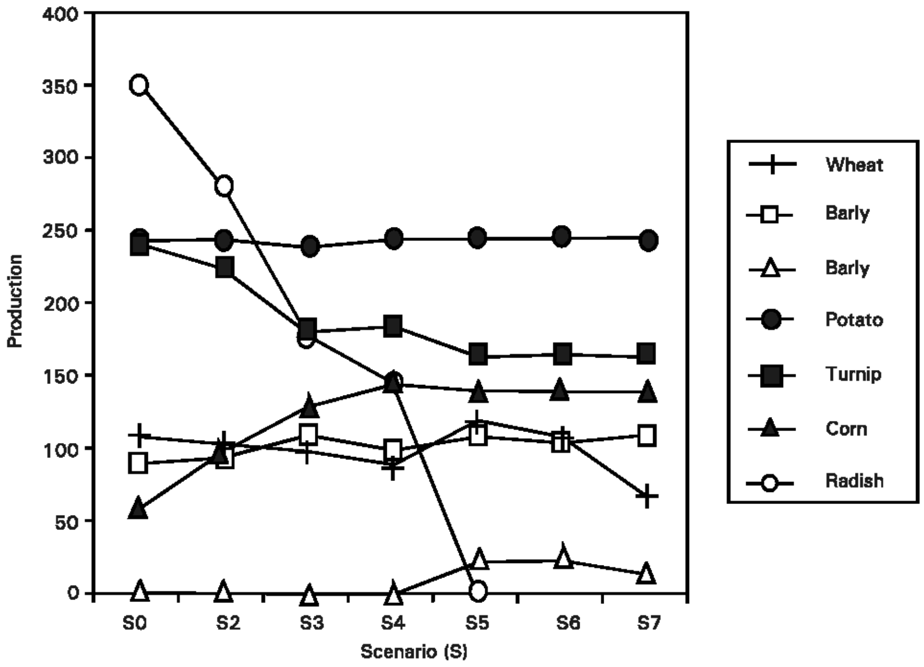

Fig. 2: Depicts the change in the quality of production (1000 ton/year) from scenario 2 to 7

Table 6: Changes in total gross margin with increasing O_3 for total plant production in the model region

	Total gross margin in	
Scenarios	1000 LE	% of S0
S0	32.61	100.0
S2	31.18	95.0
S3	29.68	91.0
S4	28.23	86.6
S5	26.83	82.3
S6	25.83	79.3
S7	18.93	58.1

from changes expected solely on the basis of dose-response functions (Fig. 2).

With regard to the requirement for production factors, an O_3-induced change from labor-intensive crops like potatoes to labor-extensive cereals (wheat, corn and barley), leads to a step-wise reduction in the demand for working hours and consequently, decreasing assignment of labor (from S5 to S7). Furthermore, increasing O_3 leads to higher costs of machinery and rapidly increasing costs for the use of pesticides. Demand for herbicides, fungicides or insecticides responds differentially because of the differences in the requirements for different pesticides between different crops. Quantity of mineral fertilizers remains fairly constant across all scenarios, but the relative need for nitrogen and phosphorus increases, while the demand for potassium declines with increasing O_3 (Fig. 2).

The analysis of O_3-induced changes in the requirement for production factors reveals that an increase in O_3 pollution in the model region is accompanied by intensification of crop production. This is manifested by the trend towards less labor-intensive but more capital-intensive (machinery, auxiliary materials) production. Possibly, this intensification could have ecological feedbacks, i.e. under increased 0; pollution intensified agriculture could cause increased environmental problems (*e.g.* pollution of water, soil and air).

The step-wise increase in O_3-level leads to a consistent reduction in the total gross margin. For instance, 30% increase in O_3 level leads to a loss of 14% in this monetary parameter, assuming that all other conditions remain constant (Table 6). On acreage, and increase in O_3 level by 10% leads to a decrease in the total gross margin by about 5%. These monetary losses would be much higher, if the adaptive response of producers, as it is taken into account by the model used here, is ignored (Heck *et al.*, 1985).

General discussion: A number of investigators have developed numerical models to explain cause-effect relationships. It is important that such models provide a balanced treatment of the stochastic O_3 exposure dynamics and the corresponding crop yield response. However, most present day models have emphasized the biology at the expense of an inadequate treatment of the O_3 exposure kinetics (Kickert and Krupa, 1991).

Ambient O_3 exposures and crop responses are considered to be inherently stochastic in nature. Profiles of ambient O_3 concentrations vary in space (altitude and latitude) and in time (year, season, month, and hour). Similarly, biological diversity and function are also highly variable in space and time since they are regulated by the variance in abiotic and biotic factors. The stochastic relationships provide an uncertainty in the results obtained with many of the existing O_3 exposure - crop response models. Uncertainty is an accepted fact in biological research. However, the degree or extent of this uncertainty can be a subject of debate where political, economic, and sociological issues are involved (Legge and Krupa, 1990; Finlason-Pitts and Pitts, 1986).

One of the key issues in modeling O_3 exposure and crop response is to identify what a control or a reference point should be in comparisons with artificial O_3 exposures or ambient exposures in present day rural areas. For example, the largest O_3 -crop loss assessment program in the world, the U.S. NCLAN (National Crop Loss Assessment Network), utilized a 7-hr seasonal average O_3 concentration of —0.025 ppm as the reference point. This has been questioned by Heuss (1982) and by Lefohn *et al.* (1989,1990). These authors state that in many rural areas of the U.S., and even in the so-called "pristine" areas of the world, hourly O_3 concentrations frequently exceed the 0.025-ppm during the growing season. While this overall debate will continue, perhaps one solution to the problem, at least for the present is to implement response surface methodology (Myers, 1971). In this approach, the number of O_3 exposure treatments is considered to be far more important than emphasizing replication of a few treatments. Since the crop response surface is more fully defined by this approach, one can numerically determine what the response will be to reference (sub-adverse effect-causing) O_3 exposure patterns at a given geographic location and growth season (Legge *et al.*, 1991). Subsequently one can compute the significance of the percent effect, if present between the gradually increasing intensities of the treatment and the reference point.

A second issue being debated at the present time is the use of open-top chambers (Manning and Krupa, 1992). These types of techniques optimize the influence of O_3 on plants while altering other variables encountered in the ambient environment (Olszyk *et al.*, 1980; 1989; Jetten, 1992). Nevertheless, the open-top chamber approach has provided the only large-scale set of data for modeling cause-effect relationships.

However, based on the preceding discussion, the most desirable approach would e the use of an appropriate chamber-less field method in assessing the effects of O_3 on crops under ambient conditions. The modeling strategy that is used could be able to apportion the contribution of O_3, relative to the contributions of their variables (e.g., other air pollutants, temperature, precipitation, pests, etc.), to the overall observed or predicted effect.

A critical issue facing modelers of O_3 exposure and crop response concerns the definition of the O_3 exposure dynamics. Numerous investigators, particularly those sing empirical or single point models, have employed single, arithmetic average O_3 concentrations of various types (Jordan *et al.*, 1988). This approach has been questioned by Krupa and Kickert (1987a). According to Jordan *et al.* (1988), the lack of correlation between vegetation exposure statistics which have been used in modeling and ambient air measurements in the U.S. has posed a major problem for those trying to assess the effects of ambient O_3 exposures.

As stated by Manning and Krupa (1992) and in Legge and Krupa (1990), in general, the frequency distributions of hourly average concentrations (all 24 hours included) of ambient O_3 exposure profiles do not exhibit a normal distribution. The computation of arithmetic means with such non-normally distributed data is statistically inappropriate and can lead to artifacts in modeling O_3 exposure - crop response relationships (Jordan *et al.*, 1988). To the contrary, use of the geometric mean or the median value free of the influence of the type of frequency distribution of the data. This approach, however, has not been used or tested in most of the O_3 exposure - crop response models to date.

Any O_3 exposure-crop response model should provide a balanced treatment of both the cause and the effect within the model. Most present day models emphasize the biology with an inadequate coverage of the exposure kinetics. If one were to identify mathematical terms that satisfactorily capture the O_3 exposure kinetics and yet provide a biological sense or significance, then the reproducibility and accuracy of single point models may be vastly improved (Krupa *et al.*, 1992). It is important to note, however, that such parameters may or may not be represented by a single value. If these types of efforts are coupled with appropriate process models, the range of parameter values could further be reduced. However, to achieve this last goal, specific experiments will have to be designed and executed.

Uncertainties: The model calculations presented here depend on large number of different data which all carry some degree of uncertainty. The validity of the results is thus strongly influenced by the combined effect of errors associated with individual data. Two main areas of uncertainty can be distinguished: (a) errors associated with experimental data and (b) limitations associated with the economic model. The data used to characterize the actual O_3 situation of the model region are derived from measurements at one selected measuring station. Extrapolation to the regional scale is difficult and could lead to errors in estimating the O_3 level used in the reference scenario, also, estimates of the natural background' level of O_3 are uncertain. Effects of O_3 on the quantity of production, or on the demand for production factor would induce restriction at the level of agricultural policy.

Such uncertainties are adherent to any empirical study dealing with complex systems. The predictions made by the model thus must be regarded as preliminary. They could, however, be used to design new research. Finally, it must be emphasized that because of the different characteristics of the agricultural and political systems in various countries, extrapolation of the results of this study beyond geographic borders is questionable.

Based on the quantitative predictions made by the model used in this study (OPTICROP), the following conclusions can be drawn:

- Today's O_3 level in Egypt represents an important limiting factor for agricultural crop production.
- Increasing or decreasing O_3 pollution has important economic consequences due to the effect on both quantity and structure of crop production.
- A decrease in feed production at elevated O_3 levels could have negative implications for animal production.
- Monetary effects of O_3 pollution are minimized by the adaptive responses of the producers, i.e. by optimizing crop rotation.

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