Application of Multi-Commodity Partial Equilibrium Model to Quantify the Welfare Benefits of Research

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Abstract

Most of the research evaluation and priority setting studies in the past are not likely to incorporate the cross-commodity effects in the estimation of welfare benefits since the cross-price elasticities are often unavailable and cross-commodity spillovers of technologies may be difficult to estimate. This paper also illustrates how the multi-commodity framework is suitable in addressing longer term trends in quantifying future welfare gains and their implications for resource allocation for dryland crops namely sorghum and groundnuts.

To address these gaps, this paper will highlight the application of multi-commodity partial equilibrium model called International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) to estimate the welfare benefits of sorghum and groundnuts research. The modelling framework also integrates crop modelling suite, hydrology model, climate models and welfare analysis. This model will endogenously estimate the changes in the production, consumption and prices due to adoption of new productivity enhancing technologies and also estimate the changes in the other commodities demand, supply and prices through cross price elasticities effects.

The returns to research investment for developing these promising cultivars and dissemination in the target countries were also estimated. The potential global net benefits derived from adoption of heat and drought tolerant cultivar in the target counties are about $302.39 million and $784.08 million with IRR of 30% and 41% respectively. The promising technology with combination of three traits (drought tolerance, heat tolerance and increased yield potential) will produce potential net benefits of $1.5 billion with IRR of 50%.

Key Words: Multi-commodity model, technology evaluation, welfare benefits

Introduction

The Consultative Group on International Agricultural Research (CGIAR) has now completed 40 years of its existence and contributed to agricultural productivity growth, poverty reduction, and environmental sustainability though its research and development activities implemented through 15 centres in different crops, natural resources and policies (Mackay and Horton, 2003; Renkow and Byerlee, 2010). Currently CGIAR is undergoing various change management by implementing CGIAR Research programs to demonstrate higher impacts on social welfare and environmental sustainability and also to prove that research and development investments in the international research represent money well spent. In this context ICRISAT joined hands with other CGIAR centers (IFPRI, CIAT, CIP, ILRI, CYMMT, ICRAF and IRRI) in advancing methodologies towards development of integrated complementary model to support priority setting.

The literature on ex-post impact assessment reveals that substantial work on assessing the impacts of a wide variety of CGIAR research using state-of-the-art evaluation techniques was done by CGIAR under Standing Panel for Impact Assessment (SPIA) and individual CGIAR institutions (Maredia, 2009; Walker et al., 2008). But under current scenarios of inherent complexities of agricultural systems with accelerating challenges - from rapidly increasing agricultural trade in high value crops to climate change to high energy prices - makes it ever more critical to provide a quantitative framework that facilitates ex-ante evaluation of possible policy and technology futures for food availability and nutrition security, particularly in the developing world. The CGIAR does not currently have a system of priority-setting that can clearly evaluate alternative investments and technological interventions to address the challenges arising from globalization and climate change.

Since there is no methodological framework to guide the allocation of resource to international agricultural research, CGIAR stressed the need for further research in this field of research planning and management. In this juncture, IFPRI (International Food Policy Research Institute) along with other CG commodity centres including ICRISAT initiated a collaborative project –

Global Futures Project – with central goal to provide the tools to assist the priority setting body of the CGIAR (currently the Independent Science and Partnership Council - ISPC) in making strategic decisions on research needs and resource allocations among the various centres. In the past, each of the research centres with the CGIAR developed its own interpretation of system goals with respect to its mandate crops, agro-ecological regions or thematic research areas. The Global Futures Project will enable CGIAR decision-makers (including management of CG centres, CGIAR Research Programs, ISPC and Fund Council) and others to better understand the consequences of income growth, diet change, climate change and other drivers on the functioning of agricultural systems and their ability to deliver services.

Most applied welfare analyses used to measure the impacts of research-induced technological changes usually appeal to single commodity models (Edwards et al., 1984; Davis et al., 1987; Alston et al., 1998; Gotsch and Wohlgenant, 2001; Bantilan and Deb, 2001). The single commodity model simplifies the analysis and facilitates disaggregation to more realistically model specified research activity impacts. The benefits and costs of research-induced technological changes are not confined to the producers and consumers of the commodity whose production is affected directly by the adoption of new technology by farmers (Alston et al., 1998). The research that affects one commodity may also affect other commodities through cross-prices effects, particularly on the demand side and also through technology spillovers.

Several past research evaluation and priority setting studies in the past are not likely to incorporate the cross-commodity effects in the estimation of welfare benefits since the cross-price elasticities are often unavailable and cross-commodity spillovers of technologies may be difficult to estimate. This paper presents address this research gap and present a multi-commodity partial equilibrium model framework to evaluate the welfare benefits of technological interventions. The paper also illustrates how the multi-commodity framework is suitable in addressing longer term trends in quantifying future welfare gains and their implications for resource allocation for groundnuts. The multi-commodity model features as

additional dimensions: i. Change in demand over time based on income and population growth; ii. Cross price elasticities; and iii. Parameter estimates validated by crop models.

The IMPACT Global Agriculture Simulation Model

The International Model for Policy Analysis of Agricultural Commodity and Trade (IMPACT) model combines a partial equilibrium model that has global coverage with hydrology and water supply and demand models and the DSSAT crop modeling suite (Nelson et al. 2010).The IMPACT model is a partial equilibrium agricultural model for 40 commodities of crop and livestock, including cereals, soybeans, roots and tubers, meats, milk, eggs, oilseeds, oilcakes/meals, sugar/sweeteners, and fruits and vegetables. The IMPACT model includes 281 spatial units, called Food Production Units (FPUs) based on 126 major river basins within 115 regions or country boundaries. The model links the various countries and regions through international trade using a series of linear and nonlinear equations to approximate the underlying production and demand functions. World agricultural commodity prices are determined annually at levels that clear international markets. Growth in crop production in each country is determined by crop and input prices, the rate of productivity growth, investment in irrigation, and water availability. Demand is a function of prices, income, and population growth. IMPACT contains four categories of commodity demand – food, feed, biofuels feedstock, and other uses.

Crop Production

Domestic crop production at the FPU-level is determined by area and yield response functions separately for irrigated and rainfed cultivation. Harvested area is specified as a response to the crop's own price, the prices of other competing crops, the projected rate of exogenous (non-price) growth trends in harvested area, and the climate stress. Commodity yield is a function of the commodity prices, the prices of inputs, climate stress, and a projected non-price exogenous trend factor. The trend factor reflects productivity growth driven by technology improvements, including crop management research, conventional plant breeding, wide-crossing and hybridization breeding, and biotechnology and transgenic breeding. Other sources of growth considered include private sector agricultural research and development, agricultural extension

and education, markets, infrastructure, and irrigation, and water. Annual production of commodity in country is then estimated as the product of its area and yield.

Supply elasticities are broken up by area, and yield elasticities. Crop area elasticities simulate the supply response to changes in own-commodity and competing commodity prices. Own-price area elasticities of supply for most products in developing countries are approximately two-thirds of those in the developed countries, reflecting the difficulties that producers in developing countries face in access to markets, information, and technology. Crop yield elasticities simulate the supply response of cropping intensity with respect to changes in crop prices, the cost of labor, and the cost of inputs. The absolute values of yield elasticities with respect to own-price, capital and labor add up to the crop price elasticity.

Demand

Domestic demand for a commodity is the sum of its demand for food, feed, biofuels, crush, and other uses. Food demand is a function of the price of the commodity and the prices of other competing commodities, per capita income, and total population. Per capita income and population increase annually according to region-specific population and income growth rates.

The IMPACT demand elasticities are originally based on USDA elasticities and adjusted to represent a synthesis of average, aggregate elasticities for each region, given the income level and distribution of urban and rural population (USDA 1998). Over time the elasticities are adjusted to accommodate the gradual shift in demand from staples to high value commodities like meat, especially in developing countries. This assumption is based on expected economic growth, increased urbanization, and continued commercialization of the agricultural sector.

Prices

Domestic prices are a function of world prices, adjusted by the effect of price policies and expressed in terms of the producer subsidy equivalent (PSE), the consumer subsidy equivalent (CSE), and the marketing margin (MI). PSEs and CSEs measure the implicit level of taxation or subsidy borne by producers or consumers relative to world prices and account for the wedge between domestic and world prices. PSEs and CSEs are based on OECD estimates and are adjusted by expert judgment to reflect regional trade dynamics (OECD 2000). MI reflects other factors such as transport and marketing costs of getting goods to market and is based on expert

opinion on the quality and availability of transportation, communication, and market infrastructure. In the model, PSEs, CSEs, and MIs are expressed as percentages of the world price. To calculate producer prices, the world price is reduced by the MI value and increased by the PSE value. Consumer prices are obtained by adding the MI value to the world price and reducing it by the CSE. The MI of the intermediate prices is smaller because wholesale instead of retail prices are used, but intermediate prices (reflecting feed prices) are otherwise calculated the same as consumer prices.

International Linkage and Trade

Regional production and demand are linked to world markets through trade. Commodity trade by region is a function of domestic production, domestic demand, and stock change. Regions with positive trade are net exporters, while those with negative values are net importers. This specification does not permit a separate identification of both importing and exporting regions of a particular commodity.

Crop Simulation Models: "Virtual" Crops

Climate change and the adoption of new technologies are two major phenomena we wish to be able to represent in the IMPACT model. Both of these are assessed using processed-based crop simulation models to provide a raw biophysical assessment which can then influence the economic model. The crop models need weather data to simulate plant growth, providing the obvious way for climate change to enter. The characteristics of particular varieties or cultivars are encoded in the genetic parameters, providing a way to create new virtual cultivars which reflect potentially desirable traits. Management specifications (e.g., planting dates, irrigation schemes, tillage regimes, etc.) open the possibility of representing further technology options. Once these are defined, the crop model can be run on a gridded basis across the world treating each gridpoint (or pixel) as an individual field.

Once the pixel level yields are generated, they must be aggregated to the regional/FPU-level for use in the rest of IMPACT. Using maps of existing production areas by crop and water source, we compute the total area, total production, and thus the area-weighted-average yield typical of the FPU under consideration. The remainder of IMPACT looks at these average yields under the various climate conditions and the baseline technology and the candidate alternate

technologies to incorporate the effects of climate change and the adoption of new technologies.

Presently, the crops modeled using the Decision Support System for Agrotechnology Transfer (DSSAT) model on a global grid are: rice, wheat, maize, groundnuts, soybeans, potatoes, and sorghum. Three virtual versions of the crops have been modeled. A drought tolerance mechanism involving deeper and more efficient roots and heat tolerance has been modeled. Similarly, drought tolerance was combined with heat tolerance and finally, the combination of drought tolerance, heat tolerance, and a high-yielding variation has been used for groundnuts.

There are some drawbacks in using process-based crop models. It is impossible to obtain even a reasonably close representation of future weather conditions and; move from coarse GCM (General Circulation Model)-level data to plot level information. Critical variables such as solar radiation which determines the plant growth are not usually available for modeling. The response of the crops to CO2 fertilization is still an active area of concern since small-scale experiments may not be realized on a large scale. Biotic stresses like pests, diseases and weeds are usually not part of crop modeling. Human response to changes in water availability and, changes in relative prices of the traditional inputs of land, labour and capital in the future are some aspects which cannot be modeled. Finally, the temporal changes in the availability of cultivable land will pose a problem in aggregating high-spatial resolution maps into FPUs.

Integrating technology adoption and welfare estimation in IMPACT framework

To allow for area and yield of multiple cultivars to respond to the price of a single commodity, some minor structural changes are made in the IMPACT modeling suite. These include the addition of a nested activity structure for the cultivars. In the IMPACT model the cultivar set is named, cul, and the members of the set are called crop1, crop2, crop3, etc. To integrate the promising and existing cultivars into the activity framework, area and yield equations must be adapted.

Harvested area

To achieve the unique shares of the cultivar areas while maintaining the same total activity area, the shares of area are applied for the cultivars accordingly. Currently in the IMPACT model, the equation for area is a function of the price of the activity, the own and cross price elasticities of the activity, and the exogenous area growth rate, described in the equation below.

$$Area_{j,FPU} = \left(1 + Areagrowth_{j,FPU}\right) * PPV_{j,cty}{}^{AreaElast_{j,jj}} * Areaint,$$

where,

$Area_{j,FPU}$	=	the total area by activity, j
$Areagrowth_{j,FPU}$	=	the total rainfed area growth over time
$PPV_{j,cty}$	=	the producer price
$AreaElast_{j,jj}$	=	the own- and cross-price elasticities for the supply response
$Areaint$	=	the area intercept

To incorporate the nested cultivar shares of the area by food production unit, the equation is adapted as follows:

$$\mathrm{Area_{cul,FPU}} = \mathrm{CulShare_{cul,FPU}} * \left(1 + \mathrm{Areagrowth_{j,FPU}}\right) * \mathrm{PPV_{j,cty}}{}^{\mathrm{AreaElast_{j,jj}}} * \mathrm{Areaint}$$

Subject to:

$$\mathrm{Area_{j,FPU}} = \sum_{\mathrm{cul}} \mathrm{Area_{cul,FPU}}$$

where,

$\mathrm{Area_{j,FPU}}$	=	the total area by activity, j
$\mathrm{Area_{cul,FPU}}$	=	the total area by cultivar, cul, for activity, j
$\mathrm{CulShare_{cul,FPU}}$	=	the share of the total area by cultivar
$\mathrm{Areagrowth_{j,FPU}}$	=	the total rainfed area growth over time
$\mathrm{PPV_{j,cty}}$	=	the producer price
$\mathrm{AreaElast_{j,jj}}$	=	the own- and cross-price elasticities for the supply response
$\mathrm{Areaint}$	=	the area intercept

Yield

The initial yield for each of the cultivars will be determined by using the yield of the activity for that food production unit which is calculated as the total production per hectare of area. The yield of the cultivars will respond to the prices of the activity, fertilizers, and wages based on the activity elasticities for each. The cultivar yield will also grow over time according to the exogenous yield growth rate.

Exogenous yield growth rate

The exogenous yield growth rate for each cultivar will be determined based on the intrinsic yield growth rate for the activity as a starting point for the growth over the time period. In the equation below, this growth rate is denoted as, a. The additional exogenous yield growth that is contributed by the promising cultivars is called b in the equation. This additional growth rate along with the productivity effect of climate change namely c will be added to the intrinsic yield growth rates, to form the rate of growth for the promising cultivars.

$$Y_{cul,FPU,t} = Y_{t-1}\left(1 + \left(a_{j,FPU} + b_{cul,fpu} + c_{j,fpu}\right)\right) * \left[\mathrm{PPV}_{\mathrm{j,cty}}{}^{\mathrm{YieldPriceElast}} * \mathrm{PFER}_{\mathrm{j,cty}}{}^{\mathrm{YieldFertElast}} * \mathrm{PWAG}_{\mathrm{j,cty}}{}^{\mathrm{YieldWageElast}}\right]$$

,

where,

Y	=	the yield for the cultivar of j in each FPU
PPV	=	the producer price
PFER	=	the price of fertilizer
PWAG	=	the cost of wages
a	=	the intrinsic productivity growth of yield
b	=	the cultivar specific productivity growth of yield
c	=	the biophysical effects on productivity growth due to climate change
YieldPriceElast	=	the own-price irrigated supply elasticity
YieldFertElast	=	the elasticity of the supply response with respect to fertilizer
YieldWageElast	=	the elasticity of the supply response with respect to wages
FPU	=	the food production unit index
cty	=	the country index
cul	=	the cultivar index
j	=	the activity index

Welfare Analysis

The welfare component of the calculations follows a traditional economic welfare analysis approach to estimate the benefits to society on the consumer- and producer-side. On the consumer-side this is straightforward, as the IMPACT model has a demand curve with demand elasticities, which allows us to calculate the consumer surplus. On the producer-side, it is not as straightforward, as the quantity supplied of each commodity is an area-yield equation, and does not represent the traditional supply curve that reflects the producer's marginal cost curve.

Therefore, we have had to create synthesized supply-curves by land-type (irrigate, rainfed, other) for each activity and then calculate the producer surplus for each of these supply-curves and then aggregate to the national level. The total changes in consumer and producer surplus, when combined, provide us with a benefit flow, which we can use in a benefit-cost analysis, to compare a technology's overall impact in the agriculture sector.

Consumer Surplus

The demand curves in the IMPACT model has income and price elasticities, and is in the following general form:

$$QF_{c,cty} = \prod \left[\left(PCV_{c,cty} \right)^{FDelas_{c,cty,c}} \right] * \left(pcGDP_{cty} \right)^{IncDmdElas_{c,cty}} * pop_{cty} * dmdint_{c,cty}$$

where,

QFc,cty	=	Quantity demanded for commodity c
PCVc,cty	=	Consumer price for commodity c
pcGDPcty	=	National per capita GDP
popcty	=	National Population
dmdintc,cty	=	Food Demand Intercept
FDelasc,cty,c	=	Own-price elasticity for commodity c
IncDmdElasc,cty	=	Income demand elasticity for commodity c

For each year and commodity, we compute the slope, m, in the equation below, of the straight line from the equilibrium point of the reference scenario (designated as subscript ref in the equations below) to the price axis using the food demand elasticity. In this calculation of the slope, we use the total quantity of food demand (QF) and the consumer prices (PC).

$$m_{ref} = \frac{1}{\varepsilon_{ref}} * \frac{p_{ref}}{q_{ref}}$$

Using this slope we can now calculate the price intercept of this line. The price intercept is the upper bound of price on consumption.

$$PInt_{ref} = p_{ref} - m_{ref} * q_{ref}$$

With the price intercept, we can now calculate the consumer surplus of the reference scenario, which will be used for all comparisons with different simulations.

$$CS_{ref} = \frac{1}{2} * (PInt_{ref} - p_{ref}) * q_{ref}$$

We envision changes between simulations and the reference scenario to be parallel shifts of the line formed by mref and the simulations' equilibrium point.

$$P_{simulation} = m_{ref} * q_{simulation} + PInt_{simulation}$$

We solve for PIntsimulation, which then allows us to compute the consumer surplus in the technology simulation.

$$CS_{simulation} = \frac{1}{2} * (PInt_{simulation} - p_{simulation}) * q_{simulation}$$

The change in consumer surplus between the simulation and the reference scenario is the difference of these two triangles.

To decompose the price and income effects we have to calculate the demand of the new simulation demand curve, but at the reference scenario prices, which we will call Q*

$$Q^* = \frac{p_{ref} - PInt_{simulation}}{m_{ref}}$$

Now, using Q* we can compute the areas of the price and income effects. First, we calculate the hypothetical consumer surplus if the equilibrium was at reference scenario prices and Q*.

$$CS_{Q^*} = \frac{1}{2} * (PInt_{simulation} - p_{ref}) * Q^*$$

Then we subtract triangles to calculate the price and income effects.

$$\text{Price Effect} = CS_{Q^*} - CS_{simulation}$$

$$\text{Income Effect} = CS_{Q^*} - CS_{ref}$$

To test if this decomposition is correct we can check to see if the following holds:

$$\Delta CS = \text{Income Effect} - \text{Price Effect}$$

Producer Surplus

To calculate the producer surplus we need to be able to calculate the area above the supply curve and under the equilibrium price. In effect, we calculate the agricultural revenue at the equilibrium point and subtract the total cost of production, which is the area under the supply curve. Without a traditional supply curve, derived directly from a marginal cost curve, we have to derive a supply-curve from IMPACT's area-yield functions, which generally speaking give us the quantity supplied (QS) in the following way.

$$QS = \text{Area} \times \text{Yield}$$

To calculate the total cost, we need to make QS a function of price. First the area and yield[1] equations as functions of their own-price (PP).

$$\text{Area} = K_{\text{area}} * PP^{\varepsilon_{\text{area}}}$$

$$\text{Yield} = K_{\text{yield}} * PP^{\varepsilon_{\text{yield}}}$$

Now we can make QS a direct function of its own-price.

$$QS = K * PP^{\varepsilon}, \text{where}$$

$$K = K_{\text{area}} \times K_{\text{yield}} \text{ and}$$

$$\varepsilon = \varepsilon_{\text{area}} + \varepsilon_{\text{yield}}$$

We then get the inverse supply function.

$$PP = P(Q) = K^{\left(\frac{1}{\varepsilon}-1\right)} \times QS^{\frac{1}{\varepsilon}}$$

Now with the inverse supply function, we are ready to calculate the producer surplus (PS), which is agricultural revenue (AR), less the total cost (TC) of production, which is the area under the inverse supply function, which we can calculate by taking the integral of P(Q)[2].

$$PS = AR - TC, \text{where}$$

$$AR = P \times QS \text{ and}$$

$$TC = \int_0^{Q_0} P(Q) = \frac{1}{\left(\frac{1}{\varepsilon}+1\right)} \times (P \times QS), \text{so}$$

$$PS = (P \times QS) - \left[\frac{1}{\left(\frac{1}{\varepsilon}+1\right)} \times (P \times QS)\right] = \left[1 - \frac{1}{\left(\frac{1}{\varepsilon}+1\right)}\right] \times P \times QS = \left[\frac{\left(\frac{1}{\varepsilon}\right)}{\left(\frac{1}{\varepsilon}+1\right)}\right] \times P \times QS$$
$$= \frac{1}{1+\varepsilon} \times P \times QS = \frac{P \times QS}{1+\varepsilon}$$

Using this equation, the producer surplus for all of the scenarios is calculated and the change in producer surplus due to technology adoption from the reference case is calculated as follows,

$$\Delta PS = PS_{\text{simulation}} - PS_{\text{ref}}$$

Cost

The cost of developing and implementing a new crop cultivar is differentiated by the source of the funding, whether it is at the global or national level. Global costs are the costs of research

[1] K_{yield} is a constant that includes growth rates, the IMPACT yield intercept, and the effects of input costs

[2] $\int_0^{Q_0} P(Q) = \int_0^{Q_0} K^{\left(\frac{1}{\varepsilon}-1\right)} \times QS^{\frac{1}{\varepsilon}} = \frac{K^{\left(\frac{1}{\varepsilon}-1\right)}}{\frac{1}{\varepsilon}+1} \times QS^{\left(\frac{1}{\varepsilon}+1\right)} = \left(QS\frac{1}{\frac{1}{\varepsilon}+1}\right) \times \left(K^{\left(\frac{1}{\varepsilon}-1\right)} \times QS^{\frac{1}{\varepsilon}}\right) = P(Q) \times \left(QS\frac{1}{\frac{1}{\varepsilon}+1}\right)$

and development that cannot be tied directly to any specific country. The role of research and development at CG centers is a good example of global costs, as the research done in developing new crop varieties is done for the benefit of many countries.

National costs are broken up into two different types of expenditures. First there is the cost of adapting a new crop variety or technology to the country-specific conditions. The cost is borne at the country-level, often by national research institutions and universities. Secondly there is the cost of agricultural extension required for the diffusion of the new technology.

This bifurcation of the costs allows for a more nuanced analysis of benefit-costs at both the national and global level. The national cost cash flow does not include global costs. This makes the assumption that from the perspective of the country that all work done at the global level (in CG centers) is a public good and is received by national research institutions free of charge. Global costs include both the global costs and the national costs.

Benefit-Cost Analysis

The Benefit-cost measures can only be used in simulations, where there is a cost component and a defined discount rate associated with a new technology. These measures can be broken up into indicators that compare simulations with their respective costs and observed changes in:

- Food Security
- Welfare

Food Security Measures

There are three food security measures, which provide insight into the effects of different simulations on food security. These measures compare simulations to show the greatest positive returns in improving food security. The following equations describe these measures:

- Food Availability: $\frac{\mathrm{Kcal}_{\mathrm{simulation}} - \mathrm{Kcal}_{\mathrm{ref}}}{\mathrm{NPV}(\mathrm{Cost}_{\mathrm{investment}})}$
- Malnourished Children: $\frac{\mathrm{Malnourished}_{\mathrm{simulation}} - \mathrm{Malnourished}_{\mathrm{ref}}}{\mathrm{NPV}(\mathrm{Cost}_{\mathrm{investment}})}$
- Share at Risk of Hunger: $\frac{\mathrm{Share}_{\mathrm{simulation}} - \mathrm{Share}_{\mathrm{ref}}}{\mathrm{NPV}(\mathrm{Cost}_{\mathrm{investment}})}$

Welfare Measures

Net Benefits and Benefit-Cost Ratio

To allow for better comparisons between the benefits of different technologies, we need to discount the benefits over time and compute the present value of change in consumer surplus and agricultural revenue between simulations. We do this by discounting future benefits at a given discount rate (r) for the years that the simulation is run.

$$\mathrm{NPV}(\mathrm{CS}_{\mathrm{simulation}}) = \sum_{i=1}^{n} \frac{\Delta \mathrm{CS}^{i}_{\mathrm{simulation}}}{(1+r)^{i}}$$

$$\mathrm{NPV}(\mathrm{AR}_{\mathrm{simulation}}) = \sum_{i=1}^{n} \frac{\Delta \mathrm{AR}^{i}_{\mathrm{simulation}}}{(1+r)^{i}}$$

$$\mathrm{NPV}(\mathrm{Total\ Benefits}_{\mathrm{simulation}}) = \mathrm{NPV}(\mathrm{CS}_{\mathrm{simulation}}) + \mathrm{NPV}(\mathrm{AR}_{\mathrm{simulation}})$$

We then need to do the same with cash flow of costs for implementing the changes in technology.

$$\mathrm{NPV}(\mathrm{Cost}_{\mathrm{simulation}}) = \sum_{i=1}^{n} \frac{\mathrm{Cost}^{i}_{\mathrm{simulation}}}{(1+r)^{i}}$$

Once we have a total benefits measure and a total cost measure we can create the Benefit-Cost ratio and calculate the Net Benefits of the technology for each crop and country.

Benefit-Cost Ratio: $\frac{\mathrm{NPV}(\mathrm{Total\ Benefits}_{\mathrm{simulation}})}{\mathrm{NPV}(\mathrm{Cost}_{\mathrm{simulation}})}$

Net Benefits: $\mathrm{NPV}(\mathrm{Total\ Benefits}_{\mathrm{simulation}}) - \mathrm{NPV}(\mathrm{Cost}_{\mathrm{simulation}})$

Summing over countries or commodities provides measures by crop and country, globally by crop, national totals, and global total.

Internal Rate of Return

In addition to the net benefits measures, we can also compute the internal rates of return (IRR) of the technology simulations. The internal rate of return of the technology is the discount rate (r)3, which makes the NPV of total cash flows (benefits – costs) equal zero.

[3] Traditionally, solving for r would require using a root solving algorithm (i.e. Secant Method, or Müller's Method). However, we can let the GAMS solver do the work for us, and solve for r by creating a basic model representing the previous relationship. As we are solving for a root,

$$NPV = \sum_{i=1}^{n} \frac{(\Delta CS^{i}_{simulation} + \Delta AR^{i}_{simulation}) - Cost^{i}_{simulation}}{(1+r)^{i}} = 0$$

Application of DSSAT groundnut model: comparison of yield advantage of groundnut promising cultivars with baseline cultivar

In this study to estimate the yield advantage of promising groundnut cultivar with traits like drought, heat and higher yield potential over the baseline cultivars, we applied DSSAT crop simulation model to develop 'virtual' promising groundnut cultivars (Singh et al. 2013). The results of the DSSAT model simulation under current climate scenario and change in climate for both baseline cultivar and virtual promising cultivars for India is presented in Table1. Using the cultivar information estimated for each region, crop yield was simulated for each pixel (10x10 Km) using spatial information on soil, climate, management, etc. and productivity change for each FPU is estimated as explained in the previous section and incorporated in the IMPACT model for evaluation.

there is an additional requirement for computing the IRR. In addition to a cash flow, the time discounted benefits must be non-negative, meaning no IRR can be calculated for any simulations where the benefits do not at least match the cost of investment.

Table 1. Effect of incorporating drought tolerance and heat tolerance traits on the mean pod yield of virtual groundnut cultivars derived from cv. JL 24 at Anantapur, India. Percent change (% change) is the yield gain due to the trait with reference to the yield of a virtual cultivar given in Table 3 for a climate scenarios.

	Baseline climate		Temperature		Temperature + CO_2		Temperature + CO_2+Rain	
Cultivar	Kg/ha	% Change	Kg/ha	% Change	Kg/ha	% Change	Kg/ha	% Change
				Drought tolerance				
Baseline	1271	3*	1049	5	1256	5	1225	5
10% short cycle	1067	5	897	5	1082	6	1054	5
10% longer cycle	1468	4	1186	5	1426	5	1373	4
Baseline + Yield pot.	1416	4	1175	5	1411	5	1376	5
10% short + Yield pot.	1184	5	1000	5	1204	5	1171	5
10% long + Yield pot.	1651	5	1324	5	1593	5	1534	4
				Heat tolerance				
Baseline	1246	1	1081	8	1299	8	1270	8
10% short cycle	1033	2	904	6	1091	6	1068	6
10% longer cycle	1461	3	1223	8	1478	9	1434	9
Baseline + Yield pot.	1382	2	1195	7	1449	7	1414	7
10% short + Yield pot.	1144	2	993	4	1199	5	1168	5
10% long + Yield pot.	1625	3	1357	8	1642	8	1588	8
				Drought tolerance + Heat tolerance				
Baseline	1292	5	1126	13	1358	13	1328	13
10% short cycle	1082	6	947	11	1139	11	1118	11
10% longer cycle	1511	7	1285	14	1546	13	1493	13
Baseline + Yield pot.	1451	7	1251	12	1510	12	1477	12
10% short + Yield pot.	1201	7	1044	10	1257	10	1231	10
10% long + Yield pot.	1694	7	1429	13	1716	13	1660	13

*Yield improvement from drought tolerance, heat tolerance, or both drought and heat tolerance compared to cultivar with same life cycle and yield potential traits within a climate scenario.

Break-up cost for developing promising cultivars

In this study we assumed that 10 million US$ is made available to ICRISAT to fund further research to develop drought tolerant cultivars. The 10 million US$ will be appropriately allocated to implement the MARC breeding method to develop the new technology as described above in previous section. The annual cost will include salary component of the researchers, field and laboratory costs and other operational costs. For conduction multi-location trails and international trail nurseries at different locations and environments, the NARS partners in target countries will be involved. The cost budgeted for carrying out this module was 1.5 million US$ in every partner country over the period of 2018 and 2019. Table 2 provides the breakup of the budget among ICRISAT and NARS partners over 8 years.

Furthermore, the extension cost borne by NARS for disseminating the new crop cultivar was about $0.8 million in each target country. This cost was spread over a period of 8 years, beginning 2020.

Table 2 Budget for ICRISAT and NARS partners (million US$)

S. No	Year	Research activities	ICRISAT	NARS partners
1	2012	Field experiments to screen and evaluate drought tolerant and Crossing the identified parents and developing F1 population	2	
2	2013	Field experiment – F2 population	1.5	
3	2014	Selection of progenies with drought tolerance using MAS	2	
4	2015	Primary yield trails (PYT)	0.75	
5	2016	Advanced yield trails (AYT)	0.75	
6	2017	Elite yield trails (YET)	0.75	
7	2018	International and Multi-location trails	0.5	0.75
8	2019	National Program trails and Release of drought tolerant variety	0.25	0.75
9	2020	Seed multiplication and make for farmers adoption		

Description of dissemination plan

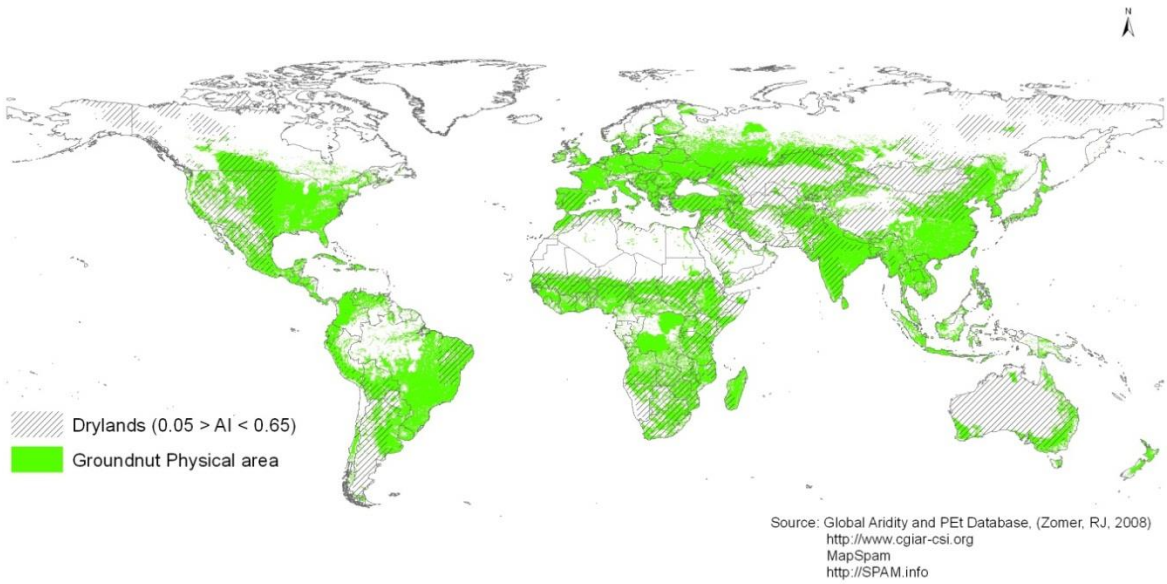
Groundnut is a smallholder crop in the target countries of Asia and Africa that is grown mainly under rainfed conditions with minimal inputs. The new technology with drought tolerant trait will produce higher yield above the baseline cultivars which farmers grows in the rainfed farming system. The new technology will also increase the resilience of the crop, so the yield will not be affected in the drought or lower rainfall. The drought tolerant technology helps to sustain the groundnut production even in the drought year.

The technology dissemination process and adoption pathways vary among countries and mainly depend on infrastructure, governance and policy environment, adaptive capacity of the NARS partners, and involvement of private seed companies or public seed banks in technology development and dissemination (Table 5).

The drought tolerant cultivar developed by ICRISAT along with partners will be released in the target countries in different regions (Table 3). The focus of drought research is to develop drought tolerant groundnut cultivar for regions/countries where groundnut is grown under rainfed condition and face frequent drought. Using aridity index, the drought prone production environment around the world is identified and mapped. The Map 1 indicates the drought prone area along with physical area where groundnut is grown. Using this Map 1 the target countries were identified for the drought tolerant technological interventions. The target countries selected are Burkina Faso, India, Vietnam, Indonesia, Mali, Nigeria, Niger, Malawi, Tanzania and Uganda which grow groundnut in dryland production environment and also prone to drought. To estimate the ex-ante welfare benefits of the research investments in the target countries, critical variables like the maximum area planted with the new cultivars (i.e. ceiling adoption level) and number of years it will take to reach the maximum adoption level are needed which are arrived at through various consultations with the breeders and using the data from similar releases in the past as a benchmark.

The adoption of the new technologies by farmers will be influenced by the profitability of the technology (depends on unit cost reduction of the new technology compared to the best available technology to the farmers), availability of the seeds to farmers at the time of sowing, government policy environments like input subsidies and infrastructures (like road networks, communication, etc.). For example in India, which is the primary target site, groundnut seed systems are dominated by the informal seed sector. Consequently the major constraints to improving groundnut productivity are the cultivation of obsolete varieties and non-availability of quality seed of improved varieties. There is very low involvement of private seed companies as groundnut seed multiplication has a low seed multiplication ratio, high volume of the seeds, storage insect pests and quick loss of seed variability. However, during the course of projects conducted by ICRISAT in the past few years, alternative seed systems have been examined for efficiency. These primarily rely on forging links between the formal public sector seed corporations (state governments, publically funded agricultural universities) and informal sector(subsidizing farmers who set up seed multiplication plots, provide certification for farmer

own multiplication plots, etc.) and have been found to be effective in multiplying and distributing improved seeds.



Map 1 Dryland environment prone to drought with groundnut physical area

Table 3 Country-wise adoption levels and adoption timeline

Region	Country	Ceiling Adoption level	Year of release of technology	Year of Maximum adoption
ESA	Malawi	60%	2020	2035
	Tanzania	40%	2020	2035
	Uganda	60%	2020	2035
WCA	Burkina Faso	40%	2020	2035
	Ghana	40%	2020	2035
	Mali	50%	2020	2035
	Nigeria	60%	2020	2035
	Niger	40%	2020	2035
SSEA	India	60%	2020	2035
	Myanmar	40%	2020	2035
	Vietnam	50%	2020	2035

Results

Potential economic benefits and return on investment of groundnut technologies

The welfare benefit of the adoption of new promising (drought, heat tolerant and combination of drought, heat and higher yield potential) cultivars of groundnut in the target countries and its impact on world price, production, consumption, change in malnutrition and poverty is assessed using IMPACT model. For this analysis, the productivity gain of the promising technologies over the baseline cultivars in each countries and regions are simulated using the DSSAT spatial crop model and incorporated in the IMPACT model and compare the baseline scenario without new technologies and simulation scenarios with the adoption of new promising technologies. The shift in the supply of the groundnut attributed to the new technologies developed from ICRISAT are likely to reduce the unit cost of production and increase the income of the farm household who adopt the technologies and reduce the market price which benefit the consumers. In the analysis, the spillover effects of promising technologies on non-target countries due to change in world groundnut production and change in world prices are identified.

Global Welfare benefits and Internal Rate of Return (IRR) of different promising technologies

The potential global welfare benefits due to the adoption of promising groundnut cultivars are given the Table 4. The potential global net benefits over a time horizon of 30 years (2020 to 2050) derived from adoption of heat and drought tolerant cultivar in the target counties are about $302.39 million and $784.08 million with IRR of 30% and 41% respectively. The promising technology with combination of three traits (drought, heat and yield potential) will produce potential net benefits of $1.5 billion with IRR of 50% (Table#).

Table 4 World potential welfare benefits and Internal Rate of Return (IRR) from groundnut technologies

Technology	Net Benefits ($M US)	IRR (%)
Heat Tolerant	302.39	0.30
Drought Tolerant	784.08	0.41
Heat + Drought + Yield Potential	1519.76	0.50

Overall producers lose some of the surplus owing to the decrease in world market price of groundnut (Figure 3). However, the negative producer surplus occurs mainly in the some non-target countries like USA, China, etc. who are major exporters offsetting the positive producer surplus gained in the target countries where the new technology is adopted. Interestingly, a few countries which were not targeted registered relatively large increases in their surplus (Figure 4). The global consumers gain significantly due to decrease in price in the world market caused by the increased production.

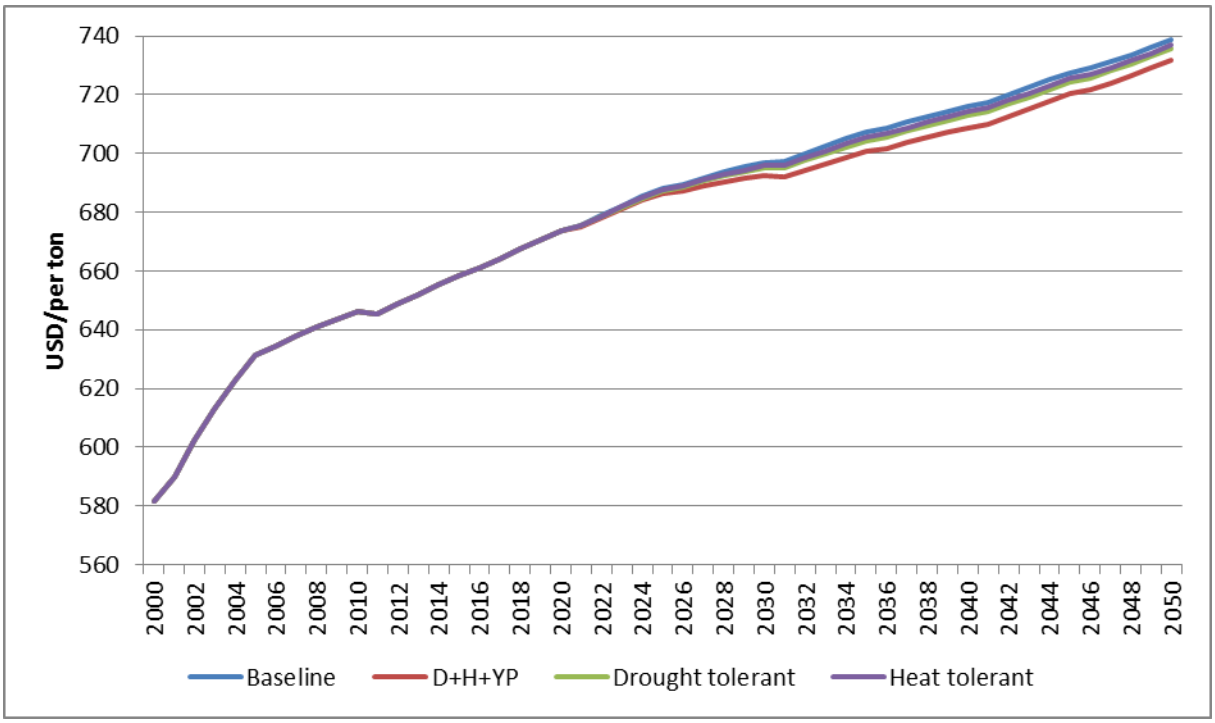


Figure 3 The world market price of groundnut under different scenarios (USD/ton)

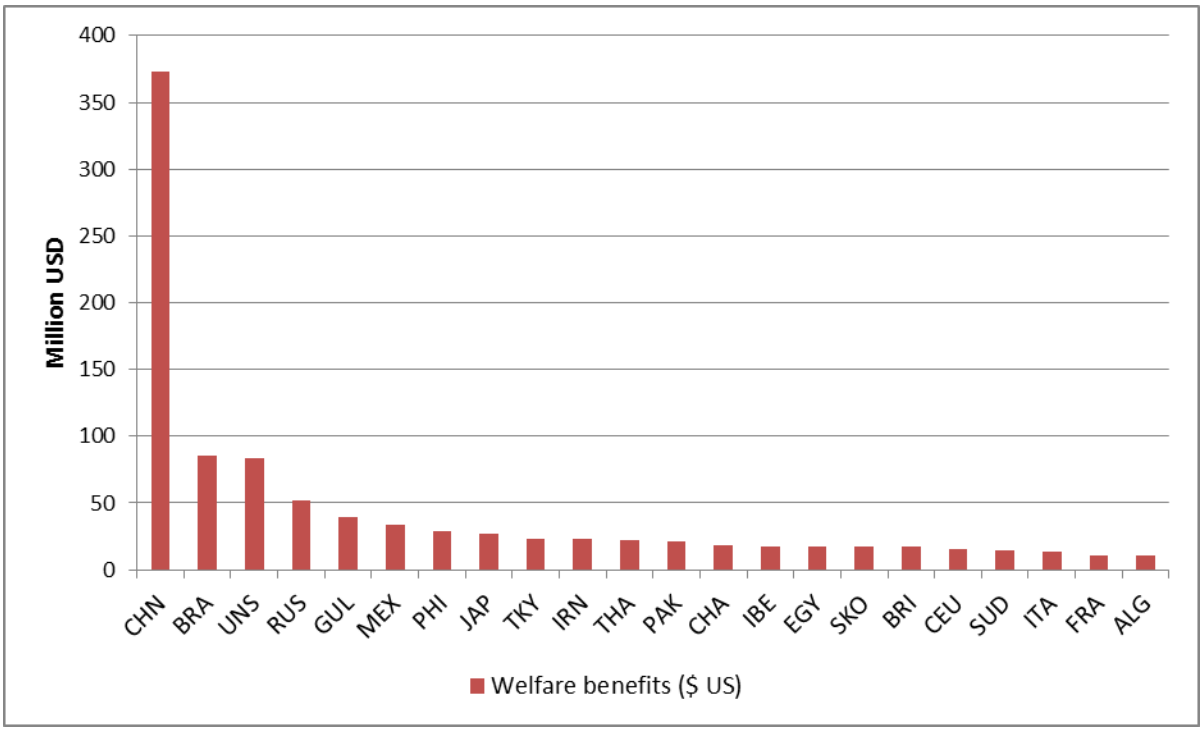


Figure 4 Welfare benefits ($M US) in the non-target countries for adoption of improved groundnut technologies (heat + drought + yield potential)

Potential economic benefits and return on investment in target countries

The estimated potential net benefits of the groundnut promising technologies developed and released in 2020 in the target countries are presented in the Table 5. The groundnut technology with combined traits like drought, heat and higher yield potential will generate higher benefits to all the target countries ranging from $286.32 to $1.47 million. The benefits are higher in India and Nigeria compare to other target counties since they are the largest producers and consumers of groundnut. The results shows that compare to heat tolerant groundnut technology the drought tolerant technology has the highest payoff in all the target countries since groundnut is grown in rainfed condition where drought is the major production constraint.

In WCA region groundnut is cultivated in marginal land with low inputs under rainfed condition, the adoption of drought tolerant with higher yield potential cultivars will generate both producer as well as consumer surplus in the target countries where the technology is adopted.

Table 5 Potential welfare benefits for groundnut technology adoption in the target countries

	Technology	Heat Tolerant		Drought Tolerant		Heat + Drought + Yield Potential	
Region	**Target Country**	**Net Benefits (M USD)**	**IRR**	**Net Benefits (M USD)**	**IRR**	**Net Benefits (M USD)**	**IRR**
ESA	Malawi	0.69	0.16	0.89	0.17	1.47	0.19
	Tanzania	0.59	0.14	3.76	0.28	8.30	0.41
	Uganda	1.01	0.18	4.09	0.28	8.66	0.40
WCA	Burkina Faso	3.63	0.34	15.28	0.86	22.49	0.99
	Ghana	0.82	0.18	0.41	0.10	2.19	0.15
	Mali	0.98	0.19	4.43	0.47	6.50	0.42
	Nigeria	23.32	0.51	37.39	0.65	64.67	0.95
	Niger	1.27	0.22	7.67	0.77	12.93	0.97
SSEA	India	37.70	0.33	129.73	0.96	286.32	1.16
	Myanmar	2.94	0.45	1.78	0.13	5.05	0.38
	Vietnam	7.31	0.58	14.34	0.80	19.28	0.74

Summary and Conclusion

In this study we used the integrated modeling framework – IMPACT – which integrates partial equilibrium economic model, hydrology model, crop simulation model and climate model to evaluate ex-ante potential economic benefits for groundnut research to develop drought, heat tolerant and combination of drought and heat tolerant with high yield potential traits. Specifically, we estimated the potential yield advantage of the promising groundnut cultivars over the baseline cultivar using crop simulation model and its impact on production, consumption, trade flow, prices of groundnut in target countries and as well as the non-target countries. And also we estimated the returns to research investment for developing the promising new cultivars and dissemination in the target countries.

Our analysis indicates that the economic benefits of promising groundnut cultivars adoption in the target countries outweigh the cost of developing these new technologies. The potential global net benefits derived from adoption of heat and drought tolerant cultivar in the target

counties are about $302.39 million and $784.08 million with IRR of 30% and 41% respectively. The promising technology with combination of three traits (drought, heat and yield potential) will produce potential net benefits of $1.5 billion with IRR of 50%. The groundnut technology with combined traits like drought, heat and higher yield potential will generate higher benefits to all the target countries ranging from $286.32 to $1.47 million. In WCA region groundnut is cultivated in marginal land with low inputs under rainfed condition, the adoption of drought tolerant with higher yield potential cultivars will generate both producer as well as consumer surplus in the target countries where the technology is adopted.

The most important limitation in this study is that only welfare effects due to changes in the groundnut kernel market have been examined. The various product markets that will benefit from the yield enhancement for groundnut are interconnected (groundnut oil and cake markets) and the spillover effects in the livestock markets are considered. Groundnut oil benefits have not been considered. Groundnut cake which is important protein rich feed resources was similarly not considered. Increased yields in both these commodities have implications for income enhancement and in contributing to enhancing livestock productivity and health.

References

Alston, J.M., Norton, G.., Pardey, P.., 1998. Science Under Scarcity: Principles and Practice for Agricultural Research and Priority Setting. CABI.

Gotsch, N., Wohlgenant, M.K., 2001. A Welfare Analysis of Biological Technical Change under Different Supply Shift Assumptions: The Case of Cocoa in Malaysia. Can. J. Agric. Econ. Can. d'agroeconomie 49, 87–104.

Mackay, R., Horton, D., 2003. Expanding the use of impact assessment and evaluation in agricultural research and development. Agric. Syst. 78, 143–165.

Maredia, M.K., 2009. Improving the Proof Evolution of and Emerging Trends in Impact Assessment Methods and Approaches in Agricultural Development.

Renkow, M., Byerlee, D., 2010. The impacts of CGIAR research: A review of recent evidence. Food Policy 35, 391–402.

Walker, T., Maredia, M.K., Rovere La, R., Kelley, T., Templeton, D., Ghraham, T., Douthwaite, B., 2008. Strategic Guidance for Ex Post Impact Assessment of Agricultural Research. Rome, Itlay.

Davis, J., Oram, P. & Ryan, J., 1987. Assessment of agricultural research priotities: an international perspective. ACIAR Monograph No 4.

Deb, U. & Bantilan, M., 2001. Spillover impacts of agricultural research: a review of studies, Patancheru: ICRISAT.

Edwards, G. W., & Freebairn, J. W., 1984. The gains from research into tradable commodities, American Journal of Agricultural Economics, 66, 4 1 -49.

Jeranyama, P., Waddington, S.R., Hesterman, O.B. and Harwood R.R. 2007. Nitrogen effects on maize yield following groundnut in rotation on smallholder farms in sub-humid Zimbabwe. African J. Biotechnol. 6:1503-1508.

Matsui, T., and B. B. Singh, 2003: Root characteristics in cowpea related to drought tolerance at the seedling stage. Exp. Agric. 39, 29–38.

Nageswara Rao, R. C., J. H. Williams, and M. Singh, 1989: Genotypic sensitivity to drought and yield potential of peanut. Agron. J. 81, 887–893

Ravi, K., Vadez, V., Isobe, S., Mir, R. R., Guo, Y., Nigam, S. N., Gowda, M. V. C., Radhakrishnan, T., Bertioli, D. J., Knapp, S. J., Varshney, R. K., 2010: Identification of several small main-effect QTLs and a large number of epistatic QTLs for drought tolerance related traits in groundnut (Arachis hypogaea L.)

Reddy, T. Y., V. R. Reddy, and V. Anbumozhi, 2003: Physiological responses of peanut (Arachis hypogaea L.) to drought stress and its amelioration: a critical review. Plant Growth Regul. 41, 75–88.

Richard R., Nelson G.C., Thomas, T. and Rosegrant. M (2012), Incorporating Process Based Crop

Simulation Models into Global Economic Analyses, American Journal of Agricultural Economics.

Sharma KK and Lavanya M. 2002. Recent developments in transgenics for abiotic stress in legumes of the semi-arid tropics. Pages 61–73 in Genetic engineering of crop plants for abiotic stress (Ivanaga M. ed.). Working Report 23. JIRCAS, Tsukuba, Japan.

Singh Piara, S. Nedumaran, B. R. Ntare, K. J. Boote, N. P. Singh, K. Srinivas, M. C. S. Bantilan, 2013, Potential benefits of drought and heat tolerance in groundnut for adaptation to climate change in India and West Africa, Mitig Adapt Strateg Glob Change, 18 (2). DOI 10.1007/s11027-012-9446-7

Taiz, L., and E. Zeiger, 2006: Stress physiology. In: L. Taiz, and E. Zeiger, eds. Plant Physiology, 4th edn, pp. 671–681. Sinauer Associates, Inc., Sunderland, MA.

Varshney RK, Graner A, Sorrells ME , 2005: Genic microsatellitemarkers in plants: features and applications. Trends Biotechnol 23:48–55

Varshney RK, Hoisington DA, Tyagi AK, 2006: Advances in cereal genomics and applications in crop breeding. Trends Biotechnol 24:490–499