Is rainfed agriculture really a pathway from poverty?

David Harris *,1, Alastair Orr

International Crops Research Institute for the Semi-Arid Tropics, East and Southern Africa, P.O. Box 39063, Nairobi, Kenya

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A B S T R A C T

Agriculture's potential to reduce poverty at household level is explored for rainfed crop production in Africa and India. A literature survey of crop improvement and natural resource management interventions demonstrates that new technology can substantially increase net returns per hectare per cropping season. However, the median net income from improved technologies was only $558/ha/season at 2005 Purchasing Power Parity (PPP) and a de facto limit of around $1700/ha/season was identified, with values rarely exceeding $1000/ha/season. These values for net returns from the literature were mostly derived from small-plot studies and are likely to be overestimates when technologies are implemented by farmers on larger areas. Crop production could be a pathway from poverty where smallholders are able to increase farm size or where markets stimulate crop diversification, commercialisation and increased farm profitability. For most smallholders, however, small farm size and limited access to markets mean that returns from improved technology are too small for crop production alone to lift them above the poverty line and the direct benefit will be improved household food security.

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1. Introduction

'Smallholders’ chances of rising out of poverty depend directly on their ability to increase the productivity of their crop and livestock husbandry activities’ (CGIAR, 2005).

Poverty reduction became a strategic objective for development in the 1990s. As donors prioritized poverty, however, they also de-prioritized agriculture. Aid spending on agriculture fell by 45% in real terms between 1990 and 2005 (Islam, 2011). Shrinking budgets intensified the pressure on agricultural research to show it could directly reduce poverty. Among international agricultural research centres, where in 2000 budgets were back to the same level as the mid-1980s (Beintema and Stads, 2008), this resulted in agriculture being promoted as a ‘pathway from poverty’. True, funding constraints have eased somewhat with the advent of new donors and a renewed consensus on the importance of agriculture for development. Nevertheless, these twin imperatives – the need to compete for scarce research funding and to demonstrate impact on poverty – continue to determine the market for agricultural research. Yet the rhetoric of poverty reduction and the emphasis on impact gloss over inconvenient truths about the structure of smallholder agriculture and variations in potential between different agricultural environments.

Agriculture’s potential to reduce poverty is rarely contextualized in terms of the farm household, or the share of agriculture in household income, or the livelihood strategies that rural households have used to graduate from poverty. Conventionally, the benefits from new technology are measured in terms of higher yields or, less commonly, income per hectare, without reference to the size of landholding or to the actual benefits that can be expected for an individual household. Similarly, where the share of agriculture in total income is low, increasing agricultural productivity will have only a modest impact on total household income. A classic example is rainfed rice in Uttar Pradesh, India, where reducing yield loss from drought increased mean income by just 1%, because rice accounted for only 9% of total household income (Singh et al., 2000). Thus, a livelihoods perspective may give a very different view of the benefits from new technology. Finally, the evidence suggests that the main driver of graduation from poverty has not been agriculture but income from non-farm sources. ICRISAT’s village studies in semi-arid India show that while between 1975 and 2004 average income per capita rose by 114%, only 4% of this increase came from agriculture and only 1% came from crop production (Badiani et al., 2007). The decisive role of non-farm income for poverty reduction is confirmed by results at the all-India level (Krishna and Shariff, 2011). Similarly, a multi-country study concluded that ‘self-employment or entrepreneurship is the most frequent path out of poverty’ (Narayan et al., 2000).

Again, a universal model of agriculture as a pathway from poverty overlooks the diversity of agro-ecological zones and farming...
systems. This is particularly true of areas where crop production is predominantly based on direct rainfall. The drylands epitomize the ‘complex, diverse, risk-prone’ environments by-passed by the Green Revolution (Chambers, 1983). Sorghum and millets, for instance, are grown in 10 major farming systems where the probability of drought leading to crop failure is one year in three, and six in ten of the rural population lives on less than $1.25 per day (ICRISAT and ICARDA, 2012). In addition, many farmers in these areas have poor access to markets. In southern Africa, for example, 75% of the rural population lives more than four hours by road from a major urban centre (Harvest Choice, 2011).

Doubts about the potential of irrigated agriculture to reduce poverty are part of a wider debate over ‘the future of small farms’ (Hazell et al., 2010). Since the 1960s, the consensus has been that equitable growth required a development strategy based on smallholder agriculture (Ellis and Biggs, 2001). This orthodoxy is now being challenged on several fronts: by those who believe that large farms are more efficient (Collier and Dercon, 2009), or that neoliberal policies have reduced the ability of small farmers to produce for the market, forcing them into non-farm activities and accelerating a process of ‘de-peasantisation’ (Bryceson, 2002), or that rural non-farm employment and urban migration offer higher returns than agriculture (Ellis, 2005). At the heart of this debate lies the future of smallholder agriculture in SSA, where 80% of farms are now below 2 ha (Nagayets, 2005; Bélières et al., 2013). Shrinking farm size has serious implications for poverty reduction, suggesting that the majority of African farms may simply be too small for agriculture to be a viable pathway from poverty. Given the present agrarian structure, therefore, current strategies to reduce poverty directly through improving yields or access to markets may benefit only a small minority of smallholders.

The implications of small farm size for strategies to reduce poverty have been addressed in two seminal papers by Jayne et al. (2003, 2010). In this article, we extend their argument to explore the implications for agricultural research. Our general objective is to test the hypothesis that the benefits from agricultural research for rainfed agriculture can raise household incomes sufficiently to reduce poverty. Specifically, we ask four questions:

1. What is the current net income from rainfed agriculture?
2. How much can new technology raise income per household?
3. What impact will this gain in income have on poverty?
4. What are the implications for the role of agricultural research in poverty reduction strategies?

We stress limitations of scope. The focus of the article is on crop production and we have excluded irrigated situations, livestock activities, fish-farming and other more investment-rich, intensive land-based enterprises. The geographic focus is on the semi-arid and dry sub-humid tropics of Africa and Asia (referred to for brevity as ‘the drylands’) where agriculture is predominantly rainfed (FAO, 2000). This is a synthetic essay that offers no new data. Rather, its originality lies in linking two separate literatures, on agricultural technology and on poverty dynamics. Our aim is not to provide definitive answers but to raise questions, challenge assumptions, and to suggest connections between farm size, new technology and livelihoods that deserve deeper investigation.

2. Data and methods

2.1. Data

2.1.1. Household surveys

The stylized facts about smallholder agriculture are captured in recent household surveys. Table 1 presents comparative data from ten surveys – nine covering seven countries in SSA plus one from India. Throughout this paper, we use these facts as a point of reference for our discussion of rainfed agriculture. The data refer only to farm households and exclude households without income from crops.

Five of the SSA surveys are national surveys that collected information on smallholder agriculture. The design of these surveys has been described elsewhere (Jayne et al., 2010). Of the remaining three surveys, two are local surveys in Malawi and Ethiopia (Asfaw et al., 2010; Simtowe et al., 2010). Although designed to collect baseline information for grain legumes, both surveys collected data for all major crops. In Ethiopia, the survey was made in three districts (Minjar-Shenkora, Gambihch and Lume-Ejere) located in the Shewa region in the central highlands. The sample size was 700 farm households, representing a proportional random sample from 26 kebeles. In Malawi, the survey was made in four districts, three in the southern region (Chiradzulu, Thyolo, and Balaka) and one district (Mchinji) in the central region. Chiradzulu and Thyolo districts are centres of production for pigeonpea while Balaka and Mchinji are centres of production for groundnuts. The sample size was 594 farm households, representing a random sample from three randomly selected villages from each of the four sections in each district producing the most pigeonpea or groundnuts. Finally, the third survey is a national household survey of Malawi conducted by the National Statistical Office in 2007–2008. A total of 10,698 households were surveyed, of which 6586 had reliable income data. Of these rural households, 4837 (86%) were defined as crop-producing households. Table 1 presents data for the sample crop-producing households, based on the published survey data (NEC, 2000a,b; GoM, 2000).

Household data for predominantly rainfed agriculture are available from ICRISAT’s Village Level Studies (VLS) in India and West Africa. For India, the most recent data presents information for six villages in Andhra Pradesh, averaged over four crop years (2001–2004). The sample size for farm households included in both the first generation VLS in 1975–1978 and the new VLS in 2001–2004 was 269 households (Badiani et al., 2007, Table 9). Table 2 lists the cases considered for this analysis. Of the 69 cases, 23 (33%) are from India, and 44 (64%) from SSA. In each case, the ‘base’ value is the net return, in $/ha/per season (converted to 2005 Purchasing Power Parity, PPP) associated with either the farmers’ practice or the ‘control’ in agronomic trials and surveys. The ‘improved’ value is the net return of the best-performing treatment or technology reported in that publication. Where original values represented annual returns in situations where there are two cropping seasons per year (e.g., in Kenya and Uganda), or where long-duration crops occupied land for more
than one season, these were divided by the number of seasons per year to be directly comparable with cropping at sites with just one season. Percentage increases over the available base case and benefit-cost ratios (BCRs) are also presented.

2.2. Methods

Costs and benefits of the base and improved technologies were converted to current US dollars using the market exchange rates at the time each study was conducted. Current dollar values were then converted to Purchasing Power Parity (PPP). The PPP values are based on household final consumer expenditure obtained by the International Comparison Program (ICP) for the benchmark year 2005 (World Bank, 2008). Since no PPP based on final consumption expenditure is available for Zimbabwe because results from the 2005 ICP were found unreliable (Ravallion et al., 2008), we used the 2005 PPP value for Zimbabwe Gross National Product.

To evaluate the benefits of improved technology at the household level, we considered the international poverty line (IPLs) of $1.25 per day per capita, expressed in 2005 PPP, developed by the World Bank (Ravallion et al., 2008). In total, information on national poverty lines (NPLs) is available for 75 countries. The $1.25 IPL is the mean PPP value of the NPLs for the 15 poorest countries, including 13 countries in SSA but excluding India, which is not among the 15 poorest. Thus, the $1.25 IPL represents an absolute poverty line or the bare minimum required for subsistence in the world’s poorest countries. By contrast, the $2 per day IPL is a relative poverty line. Above this point, NPLs rise sharply with rising consumption. The $2 per day IPL is the median 2005 PPP value for all 75 developing countries (Ravallion et al., 2008). Thus, the two IPLs represent the lower and upper bounds of the actual poverty line. Here, we use $1.25 per day because this is the IPL used by the Millennium Development Goal target of halving global poverty by 2015.

To estimate average values for ‘base’ and ‘improved’ technology, boxplots were used to identify extreme cases and outliers for the three variables, existing technology, improved, and difference between existing and improved. Five cases were subsequently dropped from the analysis (Das et al., 2008; Guto et al., 2011; Mazvimavi and Twomlow, 2009; Nedunchezhiyan, 2010; Prasad et al., 2010). The median values computed for the remaining 64 cases were 186 $/ha/season for ‘base’ and 558 $/ha/season for ‘improved’ technologies (Table 3).

‘Net income’ per ha from crop production was defined as gross returns minus variable costs, including the cost of family labour. It may be objected that this is inappropriate since peasant farms are subsistence rather than commercial enterprises. This is an old debate (Thorner, 1981). In practice, peasant farms are a hybrid, with one foot in the market and the other in the subsistence economy (Ellis, 1993). We have assumed that the published studies listed in Table 2 valued labour based on the market wage rate. Of the 69 interventions in Table 2, only 16 separated labour from other input costs. For pooled base and improved interventions, the median share of labour in total variable costs averaged 61%. Nevertheless, we believe there is a strong case for including the cost of labour.

Including labour costs, whether hired or family, is standard procedure for the evaluation of improved technology. ‘In no case requires additional labour (Anderson, 1992). We can multiply the returns minus variable costs, including the cost of family labour. It may be objected that this is inappropriate since peasant farms are subsistence rather than commercial enterprises. This is an old debate (Thorner, 1981). In practice, peasant farms are a hybrid, with one foot in the market and the other in the subsistence economy (Ellis, 1993). We have assumed that the published studies listed in Table 2 valued labour based on the market wage rate. Of the 69 interventions in Table 2, only 16 separated labour from other input costs. For pooled base and improved interventions, the median share of labour in total variable costs averaged 61%. Nevertheless, we believe there is a strong case for including the cost of labour.

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Table 2
Net returns for worst (base) case and best intervention (improved) reported since 2000 for crop- and natural resource management interventions in rainfed crop production.

| Intervention | Crop | Net returns ($/ha/ season) Current US $ | Net returns ($/ha/ season) 2005 PPP | Increase (%) | Benefit:cost ratio | Country | Reference |
|-------------|------|----------------------------------------|-------------------------------------|-------------|--------------------|---------|-----------|
|             |      | Base   | Improved | Base   | Improved | Base   | Improved |                        |                          |                      |
| a. Tillage  |      |        |          |        |          |        |          |                        |                          |                      |
| Zai planting basins + manure | Sorghum, cowpea | 0      | 127     | 0      | 276     |         |          | 1.93                  | 2.33                   | Burkina Faso cited by Haggblade et al. (2004) |
| Tillage + fertilizer (Inceptisol) 9 years | Pearl millet | 207     | 254     | 587     | 721     | 23      |          | 1.89                  | 3.52                   | India MaruthiSankar et al. (2012) |
| Tillage + fertilizer (Vertisol) 9 years | Pearl millet | 153     | 285     | 434     | 809     | 86      |          | 1.89                  | 3.52                   | India MaruthiSankar et al. (2012) |
| Tillage + fertilizer (Aridisol) 9 years | Pearl millet | 44      | 86      | 125     | 244     | 95      |          | 1.12                  | 1.26                   | India MaruthiSankar et al. (2012) |
| Tied ridges + fertilizer | Maize | 51      | 255     | 118     | 589     | 400     |          |                      |                        | Kenya Gichangi et al. (2007) |
| Tied ridges + fertilizer | Common bean | 129     | 367     | 298     | 848     | 185     |          |                      |                        | Kenya Gichangi et al. (2007) |
| Tassa planting basins | Pearl millet | 0       | 99      | 0       | 195     |         |          |                      |                        | Niger cited by Haggblade et al. (2004) |
| Conservation farming – basins | Maize | 58      | 231     | 91      | 364     | 298     |          |                      |                        | Zambia cited by Haggblade et al. (2004) |
| Conservation farming, basins | Cotton | 73      | 138     | 115     | 289     | 150     |          |                      |                        | Zambia cited by Haggblade et al. (2004) |
| Soil ripping versus plowing | Maize | 61      | 133     | 96      | 210     | 118     | 1.4      | 1.81                   |                        | Zambia cited by Haggblade et al. (2004) |
| Soil ripping versus plowing | Cotton | 76      | 91      | 120     | 144     | 20      | 1.62     | 1.67                   |                        | Zambia cited by Haggblade et al. (2004) |
| Minimum tillage + fertilizer | Maize | 50      | 77      | 79      | 121     | 54      |          |                      |                        | Zambia cited by Haggblade et al. (2004) |
| Conservation farming – basins | Maize | 48      | 535     | 369     | 4115    | 1114    | 1.76     | 4.03                   |                        | Zimbabwe Mavvimavi and Twomlow (2009) |
| b. Rotations, fallows, intercropping | Maize | –66      | 69      | –127     | 132     |         |          |                      |                        | Benin cited by Haggblade et al. (2004) |
| Improved fallows, Mucuna + fertilizer | Maize | 3       | 137     | 5      | 245     | 400     |          |                      |                        | Cameroon cited by Haggblade et al. (2004) |
| Alley cropping | Soybean, safflower, tree products | 117      | 156     | 322     | 443     | 33      | 1.88     | 2.27                   |                        | India Mutanal et al. (2009) |
| Alley cropping, discounted @ 12% | Soybean, safflower, tree products | 39       | 58      | 111     | 165     | 49      | 1.88     | 2.27                   |                        | India Mutanal et al. (2009) |
| Leucaena-based agroforestry | Cowpea, timber | 145     | 542     | 411     | 1538    | 274     | 1.86     | 3.17                   |                        | India Prasad et al. (2010) |
| Biomass retention, double cropping | Rice-vegetable sequences | 84     | 752     | 238     | 2134    | 795     | 0.46     | 1.82                   |                        | India Das et al. (2008) |
| Crop mixtures, intercropping | Wheat, lentil, toria | 101     | 437     | 287     | 1240    | 333     | 1.79     | 2.1                    |                        | India Kumar et al. (2008) |
| Intercropping | Maize, blackgram | 89      | 194     | 253     | 410     | 118     | 1.45     | 1.78                   |                        | India Sheoran et al. (2010) |
| Intercropping | Pigeonpea, maize | 123     | 346     | 349     | 982     | 181     | 2.61     | 2.75                   |                        | India Marer et al. (2007) |
| Rotations, tillage, intercropping | Maize, soybean | 247     | 435 (not sig) | 571 | 1006  | 76  | 1.81 | 2.14 | Nigeria Kihara et al. (2012) |
| Rotation | Maize, soybean | 54       | 243     | 90      | 406     | 350     | 1.22     | 2.5                    |                        | India Kolawole et al. (2007) |
| Better rotations | Wheat, sunflower, chickpea, lentil, rapeseed, vetch, peas, sorghum | 339 | 482 | 454 | 646 | 42 |          |                      |                        | Turkey Dogan et al. (2008) |
| Mucuna relay crop | Rice, maize | 197 | 407 | 460 | 949 | 107 | 1.58 | 2.13 | Uganda Kaizzi et al. (2007) |
| Watershed development, new crops, varieties and crop sequences | Maize, soybean, mungbean, groundnut, watermelon | 246 | 601 | 657 | 1604 | 144 |          |                        |                        | Vietnam MulaRosana et al. (2007) |
| Sesbania fallows | Maize | 6       | 229     | 9      | 361     | 3700    |          |                      |                        | Zambia cited by Haggblade et al. (2004) |
| Fertilizer Tree Systems | Maize | 130     | 309     | 205     | 487     | 138     |          |                      |                        | Zambia cited by Ayai et al. (2009) |
| c. Fertilizers and soil amendments | Pigeonpea | 224     | 444     | 636     | 1260    | 98      | 2.51     | 4.09                   |                        | India Singh and Yadav (2008) |
| Phosphorus and biofertilizers | Rice, niger | 175     | 303     | 497     | 860     | 73      | 2.07     | 2.21                   |                        | India Gogoi et al. (2010) |
| Fertilizer + FYM | Rice | 54       | 248     | 153     | 704     | 359     | 1.39     | 2.43                   |                        | India Deshmukh and                      |

(continued on next page)
| Intervention                        | Crop                                | Net returns ($/ha/season) Current US $ | Net returns ($/ha/season) 2005 PPP | Increase (%) | Benefit:cost ratio | Country     | Reference                        |
|------------------------------------|-------------------------------------|----------------------------------------|-------------------------------------|--------------|-------------------|-------------|---------------------------------|
| Fertilizer + mulching              | Greater yam, maize^c                | 34                                      | 633                                 | 96           | 1796              | 1762        | 0.46, 0.73                     | India    | Duhoon (2008)                   |
| Fertilizer + mulching              | Elephant’s foot yam, green gram^c    | 252                                     | 611                                 | 715          | 1734              | 142         | 1.43, 2.02                     | India    | Nedunchezhiyan et al. (2008)   |
| Foliar spraying with Calcium Nitrate| Rice                                | 194                                     | 327                                 | 550          | 928               | 69          | 0.86, 1.38                     | India    | Kundu and Sarkar (2009)         |
| Foliar spraying with Potassium Chloride | Hybrid cotton                    | 317                                     | 454                                 | 899          | 1288              | 43          | 1.87, 2.24                     | India    | Aladakatti et al. (2011)        |
| Phosphorus + VAM                   | Wheat                               | 159                                     | 268                                 | 451          | 760               | 68          | 1.55, 1.86                     | India    | Singh and Singh (2008)          |
| Soil fertility amendments          | Maize, legumes                      | 70                                      | 162                                 | 162          | 374               | 131         | 1.43, 2.22                     | Kenya    | Okalebo et al. (2007)           |
| FYM + P fertilizer                 | Maize                               | 105                                     | 365                                 | 243          | 844               | 248         | 3.23, 5.20                     | Kenya    | Odendo et al. (2007)            |
| Phosphorus, rotation               | Maize, soybean, Mucuna              | 122                                     | 478                                 | 282          | 1105              | 292         | 1.68, 3.26                     | Kenya    | Kihara et al. (2010)            |
| Micro-dosing with fertilizer       | Pearl millet                        | 83                                      | 152                                 | 164          | 300               | 83          | 1.86, 3.57                     | Kenya    | Tabor et al. (2007)             |
| Crop-livestock integration         | Maize, groundnut, soybean           | –33                                     | 413                                 | –55          | 690               | b           | 0.92, 1.72                     | Nigeria  | Franke et al. (2010)            |
| Fertilizer                         | Maize                               | 54                                      | 146                                 | 90           | 244               | 170         | 1.22, 1.47                     | Nigeria  | Kolawole et al. (2007)          |
| Micro-dosing * seed priming        | Sorghum                             | 50                                      | 206                                 | 99           | 406               | 312         | 1.82, 3.27                     | Sudan    | Aune and Ousmane (2011)         |
| Micro-dosing + seed priming        | Pearl millet                        | 45                                      | 90                                  | 89           | 178               | 100         | 1.65, 2.17                     | Sudan    | Ousmane and Ousmane (2011)      |
| Micro-dosing + seed priming        | Groundnut                           | 196                                     | 309                                 | 387          | 609               | 58          | 9.06, 9.06                     | Sudan    | Ousmane and Ousmane (2011)      |
| Micro-dosing + seed priming        | Sesame                              | 215                                     | 329                                 | 424          | 649               | 53          | 3.45, 3.45                     | Sudan    | Ousmane and Ousmane (2011)      |
| Micro-dosing + seed priming        | Cowpea                              | 69                                      | 117                                 | 136          | 231               | 70          | 1.8, 1.8                      | Sudan    | Ousmane and Ousmane (2011)      |
| Adding Azolla to the soil          | Rice                                | 65                                      | 204                                 | 152          | 476               | 214         | 1.72, 1.48                     | Uganda   | Kaizzi et al. (2007)            |
| Conventional versus Organic management | Cocoa- and vanilla-based systems^a | 290                                     | 522                                 | 676          | 1218              | 80         | 2.63, 9.21                     | Uganda   | Gibbon and Bolwig (2007)        |
| Conventional versus Organic management | Pineapple-based systems^c         | 394                                     | 630                                 | 919          | 1470              | 60          | 1.65, 24.07                    | Uganda   | Gibbon and Bolwig (2007)        |
| Conventional versus Organic management | Coffee-based systems^d             | 172                                     | 206                                 | 401          | 481               | 20          | 5.16, 6.32                     | Uganda   | Gibbon and Bolwig (2007)        |
| d. Pest and disease control        |                                     |                                        |                                     |              |                  |             |                                |                      |                                  |
| Fungicide and phosphorus           | Groundnut                           | 18                                      | 101                                 | 36           | 205               | 460         | 1.11, 1.39                     | Ghana    | Naab et al. (2009)             |
| Improved weed control              | Wheat                               | 208                                     | 398                                 | 900          | 1129              | 91          | 0.60, 1.37                     | India    | Singh et al. (2010)            |
| Push–pull for stemborer and Striga | Maize, soybean, fodder^e            | –28                                     | 283                                 | –65          | 654               | b           | 0.79, 3.16                     | Kenya    | De Groote et al. (2010)         |
| Integrated Striga Control          | Sorghum, cowpea                     | –35                                     | 283                                 | –64          | 515               | b           | –0.21, 2.02                    | Mali      | van Mourik, pers. comm. (2011)  |
| Striga control                     | Maize                               | 84                                      | 274                                 | 140          | 458               | 226         | 1.37, 3.19                     | Nigeria  | Aliyu et al. (2004)             |
| Integrated Striga Control          | Cereals, legumes                    | –88                                     | 152                                 | –147         | 254               | b           | 0.86, 1.02                     | Nigeria  | Franke et al. (2006)            |
| e. Improved varieties              |                                     |                                        |                                     |              |                  |             |                                |                      |                                  |
| Improved versus local varieties, farmers’ fields | Chickpea                     | 196                                     | 360                                 | 556          | 1021              | 84          | 4.28, 5.6                      | India    | Shiyani et al. (2001)          |
| Improved versus local varieties    | Chickpea                            | 142                                     | 199                                 | 403          | 565               | 40          | 1.34, 1.58                     | India    | Kiresur et al. (2010)          |
| Improved versus local varieties (mean over all crops in farmers’ fields) | Pearl millet, sorghum, mungbean, groundnut, wheat, barley, mustard and chickpea | 208 | 283 | 590 | 803 | 36 | 2.58 | India | Mann et al. (2009) |
| Improved variety, planting date, seed rate | Field bean (fodder) | –5 | 283 | –14 | 803 | b | 0.98, 2.89 | India | Yusufali et al. (2007) |
| Improved versus local varieties    | Pigeonpea                           | –53                                     | 24                                  | –110         | 50                | b           | 1.65, 2.17                     | Malawi   | Simtowe et al. (2010)          |
after planting coincides with the need to work off-farm in order to buy food. At peak periods, wage-labour can give higher returns than own farm production (Orr et al., 2009a). Third, in SSA, labour shortages are exacerbated by AIDS that reduces labour availability and the size of area cultivated (Niehof et al., 2010), not to mention the labour shortages experienced by households headed by women (Doss, 2001) that comprise up to one in four smallholder farms (Table 1). Finally, smallholders may derelict more than half of their income from non-farm sources (Table 1). From a livelihoods perspective, it is illogical to value family labour in agriculture at zero opportunity cost when households have alternative sources of income, however low-paid. Moreover, access to higher-paying non-farm income is a key driver of graduation from poverty. The closer households are to graduation the more important this income becomes, and the higher the opportunity cost of family labour in agriculture. From the standpoint of poverty reduction, therefore, the opportunity cost of family labour in agriculture is the income earned in non-farm activities that offer a potential pathway from poverty.

‘Income’ refers to the monetized value of crop production, without implying that all crop production is sold for cash. The analysis is based on the proposition that the contribution from crop production to the income (in $ per person per day) of each individual in a farming household depends on three factors: the total profitability of all cropping enterprises expressed as net returns in $ per hectare per year; the amount of cropped land (in hectares per household); and the number of household members. This can be expressed as the amount of land required to produce enough income for each household member to just reach the poverty line:

\[ Y = \frac{365}{X} \times n \times pl \]

where \( Y \) is the amount of land required (hectares); \( X \) the net returns from all crop production ($ per hectare per year); \( n \) the number of persons in the household; and \( pl \) is the poverty line ($ per day per capita).

The relationship between farm size and net returns from crop production was modelled using the values for farm size and crop income from six datasets from five countries in Table 1 (Jayne et al., 2001, Table 6; Simtowe et al., 2010). The data for crop income per ha was standardised to 2005 PPP values. Data for the mean farm size and farm size quartiles was pooled giving 30 observations.

The data showed large variations in the value of crop income per ha between countries. In all cases, crop income per ha declined with farm size. This is consistent with recent work by Larson et al. (2012) for Mozambique, Kenya, Malawi, Rwanda, and Zambia, which shows an inverse relationship between farm size and yield, reflecting variation in soil fertility, declining levels of labour, and sparse use of chemical fertilizer as farm size increases. However, the relationship between farm size and crop income per ha was non-linear for some countries and linear in others. An inverse function gave the best fit, but showed an implausibly steep drop in value of crop output per ha for farm below one ha. Determining the relationship between farm size and crop income per ha requires further work with additional household-level data and is beyond the scope of our paper. In view of these problems, we assumed a linear fit, using the slope derived from the pooled dataset. We assumed that the relationship between farm size and the value of crop income from improved technology would follow the same pattern. Using this simple framework, we computed the net household income from crops required to give an individual income of $1.25 per person per day as a function of farm size for situations where all, 70% or 30% of household income was from crops. We also fitted this function to the value of crop income from improved technology, assuming that the median value of net crop income from improved technology ($558/ha/season at PPP 2005) represented crop income from a farm size of 0.5 ha.

This framework assumes that the main constraint on the potential of agricultural research to reduce poverty is the availability of land. We justify this by the paper’s focus on poverty reduction. First, although labour and capital may also limit the adoption of improved technology, we show that, assuming these constraints can be overcome, the area of land required for improved crop production to lift households above the poverty line is still beyond the reach of many smallholders, particularly in India and eastern Africa. Second, poverty is concentrated in countries and regions where land is scarce. Using five of the datasets in Table 1, Jayne et al. (2003) show that, for farms below the median size, per capita income rises sharply with access to land. In summary, we are not constructing a farm model, but using a parametric budget to illustrate the binding nature of access to land on poverty reduction. Of course, this is simplistic, but it has the merit of concentrating minds on an issue – farm size – that is usually ignored in measuring benefits from agricultural research, which rarely estimates benefits at the household level.

Table 3 Average values for ‘base’ and ‘improved’ technology. Source: Table 2.

| Variable | Base | Improved |
|----------|------|----------|
| N        | 64   | 64       |
| Mean     | 260.5| 626.1    |
| Median   | 185.5| 557.5    |
| Std. deviation | 256.8 | 390.9   |
| Minimum  | 164  | 50       |
| Maximum  | 915  | 1734     |

3. Results

3.1. What is the current level of net income from dryland crop production?

Table 1 compares the results from household surveys and village-level studies. Since the surveys were made in different years, local currency units were converted to 2005 $ PPP values. Results show wide variations in income per household and income from crop production. However, in six of the household surveys, mean household income was at or below $1500 PPP per year. Mean income from crop production was below $1000 PPP per year in six surveys. In seven of the 10 surveys income from crop production per adult worker was below $450 per year, equivalent to an individual poverty line of $1.25 per day. Since we do not know how much time workers actually spent on crop agriculture, this is not a true measure of labour productivity in agriculture, and the real figure would be even lower. The figures demonstrate that crop production does not generate enough income per year to allow adult workers to live above the poverty line, and certainly does not allow support of dependents at that minimal level. Results for Malawi and Ethiopia also show disparities between the national and local surveys. Thus, using local surveys to estimate the potential impact of new crop production technology on household income and on poverty at the national level (and vice versa) may give misleading results.

The national surveys reveal three other important features of smallholder agriculture. First, the small average size of farms. Of the six SSA countries, in only three countries (Burkina Faso, Kenya, and Zambia) was average farm size above two ha, and in four countries (Malawi, Ethiopia, Rwanda, and Mozambique), average farm size was smaller than in semi-arid India. Second, the relatively high share of net household income from crop production in SSA. In four countries (Ethiopia, Rwanda, Mozambique, and Zambia) crop
production accounted for two-thirds or more of total household income while in the semi-arid villages in India the share was only one-third. Two countries in SSA – Malawi and Kenya – were close to this level, however. Third, the surveys show the importance of income from off-farm sources, contributing two-thirds of household income in India and up to one-third in some parts of SSA.

3.2. How much can new technology raise net income from rainfed crop production?

Table 2 presents the results of the literature survey, including outliers, showing levels of net income from rainfed cropping without improved technology, and the size of any likely increases following adoption of crop improvement and crop management interventions. Fig. 1 shows the ranking of net returns for both current and improved technology, not including outliers, and Table 3 presents summary statistics from Table 2. Four conclusions may be drawn.

First, net returns, excluding outliers, for the ‘base’ cases were quite low and varied from negative values (where the enterprise made a loss) to around $900/ha/season, while for improved technologies they ranged from about $120/ha/season to around $1700/ha/season. The median value of the seasonal net return from base technology was $186/ha/season and from improved technology was $558/ha/season. In absolute terms, the increase in median net returns from moving from current to improved crop production technology was $372/ha/season. Second, in percentage terms the improved technologies were very effective. In only one case did an intervention fail to improve profitability by less than 20%; in most cases the percentage increase was more than 100% and sometimes more than 1000%. Third, even with new technology, net returns above $1000/ha/season were rare and reflected unusual circumstances. For instance, one exception (Das et al., 2008) involved vegetable production after lowland rice in a very high rainfall area and net returns were calculated by assuming 100% sales – i.e. no spoilage of highly perishable produce and ready access to a market. Even apparent exceptions, such as returns from yams (Nedunchezhiyan et al., 2008; Nedunchezhiyan, 2010), fall within this range once the long duration of these crops (over 200 days, essentially equivalent to two seasons) is taken into account. Fourth, new technology gave an acceptable return on investment (BCR = 2). Information on benefit-cost ratios (BCRs) was available for 49 of the interventions in Table 2. The median BCR for base and improved technologies was 1.62 and 2.24, respectively. For the base technologies, only 18% had BCRs of 2 or over, while the share for improved technologies was 69%. Transforming base and improved BCRs to natural logarithms, a paired t-test showed that improved technology significantly improved returns to investment in crop production (t-value = −6.715, significant at 1% level).

3.3. What impact will this gain in income have on poverty at the household level?

Fig. 2 shows the relation between land area, net returns and household size represented by Eq. (1) for an IPL of $1.25/person/day. This clearly shows the effect of low returns and large household size on the area of land required to reach the poverty line. For example, with a net income of $558/ha/year from crop production (the median value for improved technology), a family of two requires 1.68 ha to reach the IPL, compared to 6.73 ha for a family of eight. Fig. 2 assumes that a given net return stays constant over the entire area of land cultivated. Keeping the same assumption, Fig. 3 shows how the area of land required to reach the IPL changes if we vary the share of household income derived from crop production. If we consider a representative household with five members who can gain a net return of $558/ha/year on all of their land, the area required to reach the IPL when all income comes from crop production is 4.15 ha. If only 70% of household income is from...
crops the area required falls to 2.9 ha and for a case where only 30% of income is from crops the area required is only 1.24 ha (Fig. 3). These smaller land areas are well within the range of farm sizes operated in SSA and India (Table 1; Nagayets, 2005; Bélières et al., 2013).

However, we know that smallholders find it difficult to maintain the same net return per hectare from a large area that they can achieve on a small area, and expect the net return from crop production to decline as farm size increases. Fig. 4 illustrates this decline based on the linear trend derived from the pooled dataset for five countries in Table 1. Assuming one cropping season per year, the net return from improved technology falls from $558/ha/season on a farm of 0.5 ha to only $415/ha/season on a farm of 4 ha. Fig. 4 also shows that the effect of farm size on household income from crops after adopting the median improved technology is slightly non-linear. Table 4 shows the numerical values derived from Fig. 4 for a range of farm sizes and share of total household income from agriculture, providing insights into the interaction between profitability, the degree of reliance of households on income from crop production, and farm size. With declining net returns per hectare as farm size increases, and assuming that all household income comes from crop production, a five-person household with 1 ha of land would derive a net annual income from adoption of the median improved technology of only $539 (a Personal Daily Income [PDI] of only 29 US cents/day), rising to $984 (a PDI of 54 cents) from 2 ha and $1660 (PDI = 91 cents) from 4 ha (Table 4).

Where income from crops is less important, the net return required also falls. In Table 4 the net returns required to reach the IPL only fall below the median value of $558/ha when cropping income is a small proportion of total income or for larger farms. When crop income is relatively important, the likelihood of reaching the IPL, even after adopting improved technologies, is small given the land areas operated by most smallholder households.

It is important to be clear on what is meant by a net return value. The relationship defined in Eq. (1) and shown in Figs. 2 and 3 uses the term in the sense that the value is the mean over all the land area considered and is thus relevant for whole-farm situations. In contrast, values from the literature shown in Table 2 and Fig. 1 and used to calculate the values in Table 3 were mostly derived from trials implemented on small pieces of land. Although they are expressed on a per hectare basis, these values will decline as the area on which they are implemented by farmers increases, as shown in Fig. 4 and Table 4. This has important implications for the practical value of improved technologies because the estimates of net returns by researchers based on small plot studies are overestimates when the technologies are adopted on larger areas (Fig. 4).

These results are illustrative only. Actual values for the required farm size and net income from crop production required to reach an income of $1.25 per day will vary. In addition, where two seasons per year are possible, e.g. through favourable rainfall patterns or by using irrigation, this will approximately halve the farm size and/or net income per season from crop production required to reach the poverty line.

4. Discussion

ICRISAT's strategy for the tropical drylands is based on the premise that 'poor people can grow their way out of poverty' (ICRISAT, 2010). What are the implications of our results for this strategy?

Disappointing research impacts have been blamed on the failure to develop innovations that are both profitable and low-risk (Anderson, 1992). There is some truth in this argument. Our literature survey identified a wide range of interventions covering almost every conceivable aspect of crop production and, as we have seen, 31% of interventions had CBVs of less than 2, which is normally considered the minimum required for adoption. Even where the CBR is above 2, it does not capture the risk of adoption or the scale of the investment required, which may make interventions inappropriate for poorer smallholders. Although some of the technologies listed in Table 2 were tested over multiple years, the average period of testing was only two seasons, and none of the publications explicitly estimated risk. Nevertheless, the results confirm the potential of new technology to raise net income from crop production. In absolute terms, the median value for net income from rainfed crop production with 'base' technology is $186/ha/season. New technology has the potential to raise this to about $558/ha/season, an increase of 200%. At the margin, this is a significant percentage gain in income. Subsidies that reduce input costs can further raise the profitability of new technology, although the increase in profitability required for improved technology to lift smallholders above the poverty line is clearly unaffordable for most developing countries. However, higher income is not the only benefit from improved technology. Improved varieties of sorghum and millet can also reduce vulnerability to drought by stabilizing yield (Deb and Bantilan, 2003). In addition, improved management practices for rainfed crops can more than compensate for the negative effects of climate change on yield, although their effect on net returns is less certain (Cooper et al., 2009). Thus, new technology can not only raise the absolute level of income from crop production but also reduce the variability of that income, although data on the variability of particular technologies is scarce.

There are two reasons for the limited impact of new technology on poverty. One is the agrarian structure. As we have seen, 80% of farms in developing countries (including 22 million farms in SSA) cultivate less than 2 ha. Rapid population growth and land fragmentation will reduce average farm size still further. As a result, in some countries and regions in SSA the agrarian structure will increasingly come to resemble that in Malawi where 'most resource-poor smallholders, even with new technologies or the ability to produce higher-value crops, will not be able to generate enough income from on-farm agricultural production to escape poverty' (Alwang and Seigel, 1999). The second reason is the low value of net returns from rainfed crop production. Table 2 suggests a de facto limit to net returns from rainfed crop production of around $1700/ha/season. The median value of $558/ha/season is similar to or sometimes higher than that found in developed countries. In the United States, for example, the net returns from maize, sorghum, wheat, barley, soybean and cotton have been in the range $40/ha to $210/ha for long periods (USDA, 2009). Similarly, in South Australia in 2009, gross margins for 11 crops in the most
businesses with the highest rainfall ranged from $197/ha (for triticale) to $751/ha (for grain vetch) with a mean of $361/ha (Rural Solutions SA, 2010). Where farm size averages 200 ha or more as in the United States such returns per farm are highly lucrative but in developing countries where most farms are 2 ha or less they mean small incomes from crop production. Let us be clear. We are not disputing the importance of agriculture for poverty reduction. There is clear evidence of a link between productivity growth and the share of the population living in poverty. A 1% increase in crop yields reduces headcount poverty for the poor by 0.91% worldwide and by 0.96% in Africa (Lin et al., 2001). Similarly, at the micro-level there is evidence that crop production is a pathway from poverty. In Kenya, for example, a national survey revealed that of the sampled households that moved out of poverty between 1997 and 2007, ‘households moving out of poverty in Uganda between 2000 and 2005, half attributed their success to investments in agriculture (Kristjanson et al., 2010). Similarly, 70% of households that moved out of poverty in Uganda between 1980 and 2004 stated that the main driver of ascent was agriculture (Krishna et al., 2006). This may seem to contradict our earlier results showing that income from new technology was not enough to lift a 2 ha farm above the poverty line. However, what matters is the process by which smallholders move out of poverty. If households graduate from poverty by acquiring more land, then crop production may not be a viable pathway for farms that stay small. Alternatively, if small farms move out of poverty through intensification or commercialisation, this suggests that crop production can generate the level of income required to make it a viable pathway from poverty.

What does the evidence show? In Kenya, panel surveys showed that between 1997 and 2007, ‘households moving out of poverty more than doubled their landholding size and cultivated 70% more land in 2007 than in 1997’ (Muyanga et al., 2010). In Mozambique between 2002 and 2005, smallholders who moved out of poverty increased their land by 10% (Cunguara, 2008). In Zambia, households moving out of poverty had increased their landholding from 5 ha at inheritance to 23 ha (Banda et al., 2011). Generally, households give more than one reason for moving out of poverty, which makes it difficult to identify a single pathway. Bigger farm size usually went hand in hand with crop diversification and commercialisation. Of the reasons given for graduation from poverty in Kenya, only 23% of households cited increased land under cultivation, compared to 49% who cited crop diversification or commercialisation. In the zone with low potential for crop production, one-half of the households moving out of poverty attributed this to crop diversification away from maize to higher-value crops (Kristjanson et al., 2010). Not all forms of commercialisation are necessarily pathways from poverty. Smallholder dairying in Kenya gave annual net returns that ranged from $889 PPP per household on farms averaging 1.2 ha and without access to communal grazing to $1348 PPP per household where farms averaged 3.6 ha and with access to communal land (Ngigi, 2005). But investment in cattle is usually seen as a sign that households have already emerged from poverty. Smallholder dairying is more of a strategy for staying above the poverty line than for climbing out of poverty (Krishna et al., 2004; Burke et al., 2007). Finally, the evidence confirms the importance of non-farm income. In Kenya, 80% of households that moved out of poverty also attributed graduation to business and non-farm employment (Kristjanson et al., 2010). This exemplifies the classic cycle in which non-farm income is invested in agriculture while agriculture generates income for non-farm investment (Ellis and Freeman, 2004).

These results suggest that there are three scenarios under which crop production may function as a direct pathway from poverty. Scenario one (Extensification) is where smallholders are able to increase farm size, allowing them to overcome the low net return from crop production by expanding the area planted. This is the same as contracting the y-axis in Fig. 2 or expanding the x-axis in Fig. 3. The second scenario (Commercialisation) is where smallholders are able to diversify and commercialize crop production in response to market demand, allowing them to increase the net value of crop production without the need to acquire additional land. This is equivalent to moving along the x-axis in Fig. 2 and coming down the y-axis in Fig. 3. Scenario three (Income Diversification) is where smallholders can increase the share of household income from non-farm sources. Some of this income may be re-invested in crop production to raise yields and improve household food security. This scenario is represented in Fig. 3. Of these three scenarios, one and three have the greatest potential as a pathway from poverty. Scenario two – crop diversification and commercialisation – requires a high level of net income from crop production. Our literature survey showed, however, that net income from high-value crops did not exceed $700/ha/season and that this was insufficient to lift a typical small farm out of poverty. In practice, small farmers attribute graduation from poverty to a combination of all three possible strategies.

These scenarios have different implications for welfare. Expanding farm size and intensification may not be feasible strategies for poorer smallholders. Bigger farm size may require investment in animal traction. In ICRISAT’s West African villages between 1985 and 2000 the area cultivated per capita rose by 75%, from 0.8 to 1.6 ha, a change due to the increased use of animal draught power (Ndjeunga and Savadogo, 2002). Similarly, crop diversification or commercialisation may be constrained by a shortage of labour. Although small farms in southern Malawi have sufficient labour for timely crop production, lack of access to credit and cash shortages make it rational for households to delay planting in order to earn off-farm income (Alwang and Seigel, 1999). Where land is still abundant, increasing farm size has no social cost, but where the land frontier has already been reached, the consequences may be different. If farms grow bigger at the expense of other small farms, then graduation through crop production may actually create poverty rather than reduce it. This highlights the need to combine crop

Table 4
Influence of non-cropping income on the required profitability of crop production for an illustrative household of five people growing one crop per year. The net returns and the HH income available from adoption of the median improved technology ($558/ha/season) are included for comparison. Values in parentheses are HH income as a percentage of the income equivalent to the IPL for five people ($2281/HH).

| Farm size (ha) | Net return required ($/ha) for $1.25/person/day | Net return from median improved technology, $/ha | Net income from median improved technology, $/HH |
|---------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
|               | 100% from crops | 70% from crops | 30% from crops |
| 0.5           | 4562             | 3193             | 1369             | 558                      | 279 (12%) | 1660 (73%) |
| 1             | 2281             | 1597             | 684              | 539                      | 339 (24%) | 1660 (73%) |
| 2             | 1141             | 798              | 342              | 492                      | 984 (43%) | 1660 (73%) |
| 3             | 760              | 532              | 228              | 455                      | 1365 (60%) | 1660 (73%) |
| 4             | 570              | 399              | 171              | 415                      | 1660 (73%) | 1660 (73%) |

Note: Italics denote values of net returns below the median value from improved technology ($558/ha/season).
production with non-farm income that does not rely on increasingly limited land.

In summary, the evidence that crop production is a direct pathway from poverty is weak. The additional income from new technology, even if adopted (and the increased investment and low returns relative to other enterprises may negatively influence adoption decisions), is not sufficient to lift a typical smallholder farm above the poverty line. True, graduation from poverty is not a one-off event based on the income from crop production for a single year, but a process. Some of this additional income can be invested and generate further income that will allow households to move out of poverty over time. However, this is unlikely unless small farms can also acquire more land, access new markets, or find higher-paying non-farm employment. Smallholders will still gain from new technology, but the primary benefits will be improved household food security, reduced risk, and the capacity to invest in assets that will generate additional income. A recent study of households graduating from poverty in Bangladesh shows the importance of improving household food security as a first step from poverty (Orr et al., 2009b). Similarly, while the Millennium Village programme in Kenya increased per capita income in 2005 PPP values by only $29 per year (a PDI of eight US cents), there was a significant impact on household food security, with a 78% increase in the quantity of maize produced and consumed by the household (Wanjala and Muradian, 2013). However, the impact of new technology on household food security has not received the same attention as the impact on poverty.

Agriculture’s main impact on poverty may be indirect. Determining the relative contribution of direct and indirect benefits is complex, since they may affect rural households simultaneously. This complexity is mirrored in the historical experience of the Green Revolution in Bangladesh, based on evidence from a panel survey between 1987 and 2000. Households that graduated from poverty did benefit directly from new rice technology: they bought land, trebled the area they planted to improved varieties, and doubled their income from rice. But this was not enough to lift them above the poverty line. The main driver of graduation was income from non-farm sources, which rose from 36% to 57% of household income (Sen, 2003). However, the Green Revolution had substantial indirect impacts. As a result of the fall in the real price of rice, agricultural wages rose from 2.7 kg to 5.1 kg of rice per day (Sen, 2003). Because the poor spend one-third of their income on rice, this was a major reason for the decline in poverty in Bangladesh since the mid-1980s (Hossain, 2010). At the global level, the Green Revolution seems to have followed a similar pattern. Had there been no Green Revolution, world rice prices in 2000 would have been at least 80% and potentially 124% higher than they actually were (Evenson and Rosegrant, 2003). Thus, the primary impact of the Green Revolution on poverty in Asia was to reduce the share of household income spent on food by effectively halving rice prices.

Indirect effects may be less important in Africa, however. General equilibrium modelling for an ‘archetype’ African economy suggests that a 10% increase in food crop productivity would increase income on small and medium farms by 3.9%, of which only 28% would be indirect, compared to direct effects of 72% (de Janvry and Sadoulet, 2002). This is because the majority of the rural poor in Africa are smallholders, not rural households without land or where most income is earned off-farm. However, most smallholders (55%) are net food buyers who would benefit from lower food prices (Larsson, 2005). Moreover, growing landlessness and rapid urbanisation will increase the share of indirect benefits from new technology. At present, however, agriculture’s ability to reduce poverty in Africa depends primarily on the direct benefits to smallholders. Our results suggest that, although new technology for crop production raises household income, the direct benefits are too small to lift most smallholders above the poverty line.

5. Conclusions

“Wealth’s buzzwords gain their purchase and power through their vague and euphemistic qualities, their capacity to embrace a multitude of possible meanings. . . . The work that these words do for development is to place the sanctity of its goals beyond reproach” (Cornwall, 2007).

What exactly do we mean when we say that agriculture is a pathway from poverty? Are we suggesting new technology is so profitable that it alone can provide every member of a poor farm household with more than $1.25 per day? Alternatively, are we suggesting that agriculture alone is not enough for farmers to graduate from poverty, but that investment in agriculture is an essential precondition? For which farmers? Which crops? In which environments? Like other development buzzwords, the rhetoric of poverty reduction is rich in imprecision.

The evidence suggests that there are two situations where crop production can be a pathway from poverty. The first is where smallholders can acquire land to increase farm size. This is still possible in some African countries but less feasible in South Asia and in many parts of eastern Africa where the land frontier has already been reached and extensification may exacerbate poverty. The second is where new markets stimulate demand for crop diversification towards higher-value crops or commercialisation. For small farms unable to increase farm size or without higher prices through access to better-functioning markets, however, the evidence suggests that crop production is not a viable pathway from poverty. The returns from improved technology are too low and farms are too small to produce the income required to lift a typical smallholder family above the poverty line. For such farmers, the direct benefit from new technology will be to provide a stable foundation of food security that, if not accompanied by increased risk, provides a stepping stone from poverty but not a complete pathway.

Agriculture’s contribution to poverty reduction is not in dispute but this contribution needs to be more carefully specified, taking account of small farm size and the low agronomic potential of rain-fed agriculture. These suggest the need to modify overly optimistic views about the ability of crop production in the drylands to reduce poverty. For most small farms in the drylands, improved technology for crop production is not and cannot be a pathway from poverty. This conclusion makes uncomfortable reading but may challenge others to re-think the potential of agricultural research to reduce poverty in the drylands.

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