

1 Global Assessment of Redesigned Sustainable Intensification of Agriculture

2 Supplementary Information

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4 We developed a typology of seven redesign types according to starting intervention: (i) integrated
5 pest management, (ii) conservation agriculture, (iii) integrated crop and biodiversity, (iv) pasture and
6 forage, (v) trees in agricultural systems, (vi) irrigation water management and (vii) intensive small
7 and patch systems. Summary details of each are presented here with examples of illustrative sub-
8 types. The supplementary table contains details of all 47 initiatives included in the global assessment
9 (Table S1).

10 11 Type 1. Integrated Pest Management

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13 The most significant design innovation for IPM has been the deployment of Farmer Field Schools
14 (FFS) (1). The aims are education, co-learning and experiential learning so that farmers' innovative
15 expertise is improved. FFS are not only an extension method but also increase knowledge of
16 agroecology, problem-solving skills, group building and political strength. FFS have now been used in
17 90 countries (2-3), with some 19M farmer graduates, 20,000 of whom are running FFS for other
18 farmers as expert trainers. A synthesis of evidence from 92 impact evaluations of FFS related to IPM
19 found a 13% increase in yield and 20% increase in income following engagement with FFS (4). A
20 specific application of agroecological principles for IPM is *push-pull*, which is yielding notable
21 successes from redesign of monocropped maize, millet and sorghum systems (5-6). Interplanting of
22 the legume forage *Desmodium* suppresses *Striga* and repels stem borer adults while attracting
23 natural enemies; planting *Napier* grass as a border crop pulls stem borer moths from the cereal. It is
24 estimated that 132,000 farmers have adopted push-pull in Kenya, Uganda, Tanzania and Ethiopia (5).
25 Positive externalities arise from nitrogen fixation by *Desmodium* and elimination of pesticides, in the
26 provision of high quality fodder, enabling farmers to diversify into dairy and poultry production, in
27 turn increasing the availability of animal manure for crops and soils. One meta-analysis of 85 IPM
28 projects found a mean yield increase across projects and crops of 41%, combined with a decline in
29 pesticide use to 31% compared with the baseline (7); another multi-country study of SI in rice-based
30 systems of China, Thailand and Vietnam found yield increases of 5% with pesticide use reductions of
31 70% (8).

32 33 Type 2. Conservation Agriculture

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35 A central principle of this redesign type is improved soil health. A variety of measures to mitigate soil
36 erosion, improve water-holding capacity and increase soil organic matter are being deployed to
37 improve soil health and boost crop yields. Three key features are reduced soil disturbance through
38 reduced or zero tillage, mulching and green manures, and maintenance of year-round soil cover and
39 crop rotations, seeking to maintain an optimum environment in the root zone in terms of water
40 availability, soil structure and biotic activity (9-11). Optimal CA uses all three features, though many
41 farmers only practice one or two of these. Currently, CA systems are practiced across a range of
42 agro-ecological conditions, soil types and farm sizes. CA practices are spreading by some 6 Mha
43 annually to a total of 180 Mha in 2017. CA covers >50% arable cropland in Australasia and South
44 America, 15% of North America, though adoption has been lower across Europe and Africa.

46 Type 3. Integrated Crop and Biodiversity Redesign

47

48 In both industrialised and developing countries, a growing number of crop systems have been
49 redesigned using agro-ecological principles. A worldwide example of redesign is organic agriculture,
50 now occupying 58 Mha, with yields 5-50% lower than conventional equivalents, though under
51 certain conditions organic yields can match or exceed conventional (12-14). With a wide range of
52 approaches including livestock, pasture, agroforestry and small-scale horticulture, many organic
53 systems have higher biodiversity, landscape diversity and soil carbon, and lower soil erosion and
54 contamination of water systems (15), though some of these benefits come from uncultivated
55 habitats. However, organic systems are generally more profitable, thanks in part to legally-regulated
56 markets, and environmentally friendly, and deliver equally or more nutritious foods that contain
57 fewer pesticide residues. Over the past decade, the number of organic producers has grown by 55%
58 and organic area doubled, and there have been recent calls for a *beyond organic* or *organic 3.0*,
59 focusing on sustainability goals rather than market definitions (12, 16-17). The largest number of
60 organic farmers are in India, Ethiopia, Mexico and Uganda; the largest area in Australia and
61 Argentina, and the largest proportions of country cropland in Austria, Liechtenstein and Samoa (13).

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63 Further redesign and deployment of multiple interventions has seen increased rotational diversity,
64 use of wildflowers for pollinators and other beneficial insects, conservation headlands and trap
65 crops, composted animal manures, and grain legumes (18-20), often with large reductions in input
66 use without yield compromise, such as on 750 farms in France (21). In less-developed countries, fish,
67 crab, turtle and duck have been reintroduced into rice systems, reducing pest and weed incidence,
68 often eliminating the need for pesticides, and thus producing increased system productivity through
69 new animal protein (22). Both the Systems of Rice and Crop Intensification (SRI and SCI) emerged
70 from complete redesign of paddy rice cultivation: reduced planting density, improvement of soil
71 with organic matter, reduced use of water, and very early transplantation of young plants have led
72 to considerable yield increases with reduced requirements for water and other external inputs (23-
73 24). Since inception, SRI principles have been adapted from rice to wheat, sugarcane, tef, finger
74 millet and pulses, all again emphasizing changes in resource use and application combined with crop
75 planting design. The governments of Cambodia, China, India, Indonesia and Vietnam have endorsed
76 SRI/SCI methods in their national food security programmes, with one million Vietnamese rice
77 farmers now using SRI.

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79 Type 4. Pasture Redesign

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81 Pasture redesign has arisen from diversification of cropping, including organic agriculture, the
82 adoption of Management Intensive Rotation Grazing (MIRG), and the deployment of agro-pastoral
83 field schools (25). In Brazil, redesigned *Brachiaria* forages in maize-rice and millet-sorghum systems
84 have through increased net productivity led to large increases in all-year forage, which is used both
85 for livestock and as a green manure (26). MIRGs are an example of widespread pasture redesign,
86 using short-duration grazing episodes on small paddocks or temporarily fenced areas, with longer
87 rest periods that allow grassland plants to regrow before grazing returns (27). These systems replace
88 external inputs including feed with knowledge and high levels of active management to maintain
89 grassland productivity. Well-managed grazing systems have been associated with greater temporal
90 and spatial diversity of plant species, increased carbon sequestration, reduced soil erosion,

91 improved wildlife habitat and decreased input use (28). As many have replaced zero-grazed confined
92 livestock systems, the animals themselves have to be bred for different characteristics: large mouth,
93 shorter legs, stronger feet and hooves, larger rumen. MIRGs were first developed in New Zealand,
94 and are now common in parts of the USA.

95

96 Type 5. Trees in Agricultural Systems

97 Agroforestry has long been used in traditional agricultural systems, particularly in the tropics (29).
98 Two types of deliberate redesign have been deployed with trees and shrubs: i) their introduction
99 into cropped systems, and ii) new forms of collective management of woodland and forest within
100 agricultural landscapes. Legume tree-based farming systems offer a route to increased availability of
101 nitrogen while avoiding synthetic fertilizers, leading to the use of the term *fertilizer tree* (30). Shrubs
102 (e.g., *Gliricidia*, *Sesbania*) are introduced into crop rotations, increasing fuelwood production and
103 nitrogen fixation, but still increasing net cereal yield over a five-year rotation. In other systems,
104 perennial trees (e.g., *Faidherbia*) are introduced into dryland and silvo-pastoral systems, with trees
105 leafing when crops are not growing, resulting in re-greening of some 5Mha in Niger, Burkina Faso
106 and Mali, with the outcome of amended local climate, increased wood and tree fodder availability,
107 and better water harvesting (31-32). The success of community-based, joint and participatory forest
108 management has centered on the reversal of past state policy to exclude local people. Local
109 management through new forest institutions, plus devolution of practices, rules and sanctions, have
110 led to the formation of 3000 groups in Mexico, 30,000 in India and Nepal, 1.8M farmers in Vietnam
111 with tree certificates, and 12M forest farmer cooperative users in China (33-34). There is renewed
112 interest in agroforestry in temperate systems, particularly in France and the UK (16).

113

114 Type 6. Irrigation Water Management

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116 Without regulation or control, irrigation water tends to be overused by those who have first access,
117 resulting in shortages for tail-enders, conflicts over water allocation, and waterlogging, drainage and
118 salinity problems (34). However where social capital is well-developed, water-user groups with
119 locally developed rules and sanctions are able to make more of existing resources than individuals
120 working alone or in competition (35-36). This increases rice yields, farmer contributions to design
121 and maintenance of systems, changes in the efficiency and equity of water use, decreased
122 breakdown of systems and fewer complaints to government departments. More than 60,000 water-
123 user groups and associations have been established in India, Indonesia, Mexico, Nepal, Pakistan, the
124 Philippines, Sri Lanka, Turkey and Uzbekistan, though many exist only on paper or remain in
125 inefficient centralised control (37-42).

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127 Type 7. Intensive Small and Patch Systems

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129 The intensive use of patches (small areas of land) can be effective, particularly for cultivation of
130 vegetables or rearing fish, poultry or small livestock. These may be located in gardens, at field
131 boundaries, in urban or rural landscapes, and managed individually or collectively. Examples in
132 industrialised countries include allotments, community gardens or farms, vertical and urban farms,
133 and community supported agriculture. In developing countries, patch intensification for aquaculture
134 ponds and tanks has been shown to raise protein production, reduce nitrogen requirements for

135 crops, and positively impact agricultural productivity (43). Raised beds for vegetables in East Africa
 136 have been beneficial for large numbers of women, homestead garden production has spread in
 137 Bangladesh, and in China full redesign has been exemplified by integrated vegetable and fruit, pig
 138 and poultry farms with biogas digesters. Farm plots are very small (0.14 ha), and yet farmers are able
 139 to recycle wastes, produce methane for cooking, and reduce burning of wood and crop residues,
 140 with implementation on 50 M household plots in China (44-46). An important enabler of small-scale
 141 intensification has been provided by access to microcredit. When local groups are trusted to manage
 142 financial resources, they are more effective than banks, leading to positive agricultural and
 143 community outcomes. All form social groups, all work primarily with women, and all members of
 144 groups save money every week in order to create the capital for lending. In Bangladesh, Grameen
 145 Bank, Bangladesh Rural Advancement Committee, and Proshika have 1.5M groups with 17M
 146 members: many have diversified into social enterprises for rural artisans, providing livestock
 147 insemination services, chicken for retail, cold storage for potato farmers, dairy milk processing,
 148 services for fish farmers, tree seedlings, iodised salt, seed services, and sericulture (silk production)
 149 (47-49).

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152 **Supplementary Table S1. Global assessment of sustainable intensification redesign from 47 initiatives at**
 153 **scale**

Redesign type	Illustrative sub-types	Country	Farm numbers (million)	Hectares under SI (million)
1. Integrated pest management (IPM) ⁵⁰⁻⁵⁹	Farmer field schools for integrated pest management	Worldwide, 90 countries in Asia and Africa: especially Indonesia, Philippines, China, Vietnam, Bangladesh, India, Sri Lanka, Nepal, Burkina Faso, Senegal, Kenya	19.0	15.0
	Biological control of pearl millet head miner	Burkina Faso, Niger, Mali, Senegal	0.75	2.0
	Cotton integrated pest management	Egypt	0.15	0.31
	Push-pull IPM	Kenya, Uganda	0.13	0.10
2. Conservation agriculture ⁶⁰⁻⁶⁵	Conservation agriculture with zero-tillage	Worldwide: Brazil, Argentina, Kazakhstan, USA, Australia, India		
		Industrialised countries	0.45	94.0
		Developing countries	16.5	86.0
	Microbasia groups for watershed management	Brazil, southern: Parana, Santa Catarina	0.10	1.0
	Zai and tassa water harvesting	Burkina Faso, Niger	0.05	0.025
3. Integrated crop and biodiversity redesign ⁶⁶⁻⁸³	Organic agriculture	Worldwide: especially India, Ethiopia, Mexico (for numbers of farmers)	2.70	57.8
	Rice-fish systems	South-East and East Asia	1.0	1.4
	System of Crop and Rice Intensification, multiple crops	Ethiopia, Vietnam, India	3.113	3.013
	Pigeon pea/maize multiple cropping	East and Southern Africa	0.45	0.25
	Crop redesign with	Burkina Faso, Niger, Mali,	0.18	0.15

	integrated plant and pest management with farmer field schools	Senegal			
	Landcare	Australia	0.09	0*	
	Campesino a Campesino agro-ecological farming	Cuba	0.10	0.05	
	Zero-budget natural farming	India: Andhra Pradesh	0.163	0.081	
	Farmer agro-ecological wisdom networks	NE Thailand	0.10	0.30	
	Science and technology boards	China	0.05	0.03	
	Legume-maize intercrops for green manures/cover crops	Honduras, Guatemala, Mexico, Nicaragua	0.067	0.090	
	Green manure/cover crop mixed systems	Brazil	0.14	0.10	
	All crops with mucuna legumes (for <i>Imperata</i> suppression)	Benin	0.014	0.03	
	Mokichi Okada natural/nature farming	Japan	0.015	0.003	
	Orange-fleshed short-duration sweet potato	Uganda	0.014	0.011	
4.	Pasture and forage redesign ⁸⁴⁻⁸⁸	Management intensive rotational grazing	USA	0.01	1.6
		Brachiaria-grass mixed crop-forage systems	Brazil	1.3	80.0
		Agro-pastoral field schools	Uganda	0.12	0.25
5.	Trees in agricultural systems ⁸⁹⁻¹⁰⁰	Agroforestry and soil conservation	Niger, Burkina Faso, Mali	4.0	3.0
		Joint forest management groups and forest protection committees	India, Nepal	11.6	25.0
		Community based forestry	Mexico	0.09	15.0
		Forest farmer cooperatives	China, Vietnam	13.80	17.8
		Agroforestry and multifunctional agriculture	Cameroon	0.010	0.005
		Fertilizer and fodder trees and shrubs	Zambia, Malawi	0.50	0.40
6.	Irrigation water management ¹⁰¹⁻¹⁰⁴	Water user associations for irrigation management	India	15.0	15.0
		Community irrigation management subaks	Indonesia (Bali)	0.90	14.0
		Water users associations	Mexico	2.0	4.0
7.	Intensive small and patch systems ¹⁰⁵⁻¹¹⁶	Microcredit group programmes (enablers of small-scale SI): BRAC, Grameen, Proshika	Bangladesh	17.0	8.50
		Intensive vegetable-pig systems with biodigesters	China	50.0	7.0
		Homestead garden production	Bangladesh	0.94	0.01
		Organic small-scale raised beds	Kenya	0.15	0.001
		Allotment gardens	UK	0.30	0.0075

Community urban gardens	USA and Canada	0.018	0.001
Group purchasing associations (Community Supported Agriculture, tekei groups, guilds)	USA, France, Japan, Switzerland, Belgium	0.011	0.055
Integrated aquaculture	Malawi, Cameroon, Ghana	0.018	0.001
Total		163	453

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Note: we do not present data on adoption of GM crops here, as these have mostly resulted in Efficiency/Substitution changes: one crop variety for another, some reductions in insecticide, some increases in herbicide, depending on the traits (Frisvold and Reeves, 2014); a number of GM traits are used in conservation agriculture systems.

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*The average farm size in Australia is 3000 hectares, but there is no data on area under SI within Landcare groups and farms.

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162 References for Supplementary Text and Table

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164 References for Supplementary Text

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