Chapter 16
Step-By-Step Along the Path to Sustainability

Hans Ramseier, Michaela Burkhart-Pastor, Sabrina Lüthi, and Christian Ramseier

Abstract FAO estimates that agricultural production must increase by about 50% by 2050 to meet the needs of the growing human population and our growing demand for meat and dairy products; this against a backdrop of shrinking farmland. If more food is to be produced on less land in the long term, it needs to be done in the most resource-efficient way. Consistent integrated farming systems, organic farming, intercropping, under-sowing and green manures are all potential ways of moving step-by-step towards sustainability. However, consumers must also be prepared to adapt their eating habits and to pay the proper price for food; governments have to create corresponding policy and legal frameworks; and the challenge for agricultural research is to develop more productive, more resource-efficient farming systems suited to diverse regional conditions.

Keywords Sustainable agriculture · Mixed crops · Under-sowing · Green manures

Introduction

Agriculture is at a crossroads. In 2018, 2.65 billion tonne of grain was harvested worldwide, more than ever before, but the harvest is far from equally distributed—more than 800 million people are starving, and at the same time, nearly 2 billion are overweight. Only 40% of the food produced is used directly as food; the rest is processed into stock feed, fuel and industrial raw materials (World Agricultural Report 2019). These are risky trade-offs between food, stock feed, bio-fuel, human well-being and ecological stability.

Agriculture and the food system as a whole face big challenges. The UN estimates that human population will increase to about ten billion by 2050. Nearly, all this growth will take place in what are, at present, low- and middle-income countries where diets are switching towards greater consumption of meat and dairy products so, if this pattern of demand is maintained, agricultural production will have to

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increase by around 50% over 2013 levels (FAO 2017). A further point, especially relevant to the Western world, relates to high-quality requirements and food waste; for example, in Switzerland, one third of all food does not even reach the table (FOEN 2018).

Farmland is shrinking worldwide. The German Environment Agency estimates that ten million hectares of farmland are lost every year; and a quarter of global soils have significantly less humus and nutrients than 25 years ago or can no longer be used for farming at all (UBA 2015). And, yet, food has become cheaper and cheaper so that the average consumer spends less and less of his or her income on food (Allan and Dent 2021); in Switzerland, this figure was just a little over 6% in 2016 (FSO 2019).

All these factors have far-reaching consequences for food and farming. At the same time, there has been a global trend towards specialisation and bigger farms; workforce productivity has greatly increased so that immense amounts of food are produced per worker; farming systems are simplified to the point of monocropping. To maintain systems of this sort requires correspondingly greater inputs of fertiliser, plant protection products and water. This may be profitable in the short term but it is certainly not sustainable in the longer term. So, what is the sustainable alternative? On the one hand, we must bring tried-and-tested traditional knowledge to modern farming systems but, on the other hand, we need innovation. Let us consider some approaches in more detail.

Consistent Integrated Farming

Essentially, integrated farming systems support the agro-ecosystem and the health of crops with as little-as-possible direct interference with natural conditions—by making use of preventive measures such as crop selection (e.g. suitable location), variety selection, crop rotation, attention to the health of the soil and the crops, cultivation technique, plant nutrition and encouragement of beneficial insects (Fig. 16.1).

To this end, valuable assistance can be provided by decision-making tools like early warning systems, prognostic and expert systems, and recognition of pest-control thresholds. Should direct intervention become necessary, then mechanical, biological and bio-technological measures are employed in the first instance. Chemical/synthetic products are a last resort and, if at all possible, selective chemicals should take precedence over broad-spectrum agents. The aim is to achieve optimal effectiveness while minimising unwanted side effects. Compared with conventional farming, rigorously implemented integrated farming can increase productivity through savings on input costs without any loss of yield.

In recent years, we have made several field trials comparing the integrated approach with conventional systems. For example, in trials on 13 farms with an integrated approach employing 0–1 fungicide treatment as opposed to the conventional approach employing 2–3 fungicide treatments, yields of winter wheat under

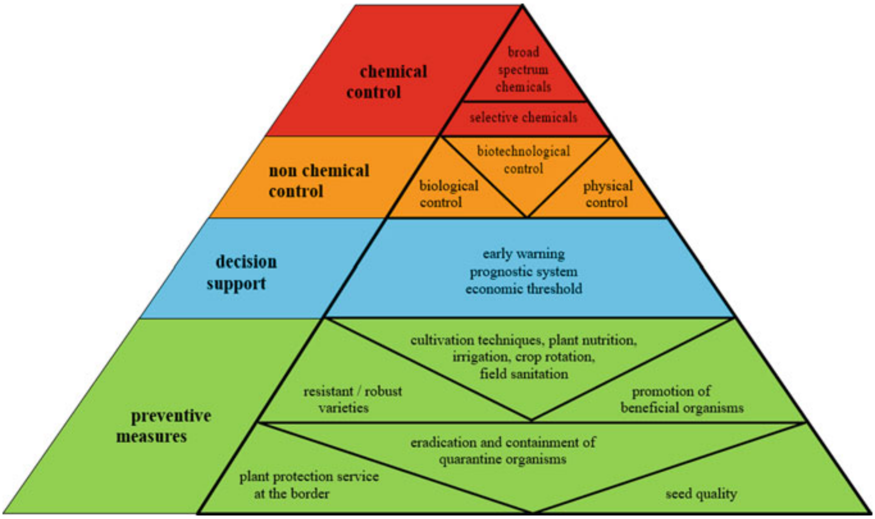

Fig. 16.1 Principle of integrated pest management. The classic IPM pyramid shows the measures that agricultural producers can introduce on their farms. This expanded diagram also includes measures at national level (lower section: preventive measures). *Source* Federal Office for Agriculture, Switzerland

conventional practice averaged 78.6 dt/ha; and under integrated practice 74.8 dt/ha. In block trials with 4 replicates at two locations in 2019, winter barley yielded 96.9 dt/ha under conventional practice and 95.3 dt/ha under integrated practice. Thanks to lower input costs, the financial returns from the integrated system are equal, if not better.

Organic Farming

The objective in organic farming is similar to the rigorous approach taken in integrated farming but with even more weight on integrating the whole farm operation and cycling of materials; absolutely no synthetic chemical plant protection products or freely soluble mineral fertilisers are used. In the lowlands of Switzerland, organic farms used to be traditional, mixed livestock and arable farms, which meant that closed nutrient cycles were achievable, and there were very few available and approved pesticides. Nowadays, with the promotion of organic farming, there are more and more organic farms with few livestock or, even, no animals at all. Moreover, the number of approved organic crop protection products has risen significantly.

Intercropping

Intercropping is one option for using the available natural resources more efficiently. It is traditional in the tropics and, formerly, also in Western Europe; indeed, mixed crops were and are the standard forage crops in Switzerland so adopting intercropping is, actually, 'back to the future'. There are countless variants: for example, companion crops can be sown within the same row, in separate alternate rows, or mixed sowings over a wide area. One special form of mixed planting is *relay intercropping*, where crops are not only mixed in the field but one is sown later than the other. Relay intercropping was developed in regions where planting two main crops consecutively (double cropping) is not viable because the growing season is too short (Howard 2016).

Martin-Guay et al. (2017) considered the wealth of advantages of intercropping. Their analysis of 939 investigations from 126 studies worldwide shows that, where companion crops were planted, total yields were usually greater than where one crop was grown alone—even under stressful conditions like drought (Himmelstein et al. 2016). Depending on the focus of the investigations, further advantages of intercropping were proven for each location: greater and more reliable yields, greater diversity, better pest and disease control and lower weed pressure (Malézieux et al. 2009; Lithourgidis et al. 2011; Chapagain and Riseman 2014). They conclude that intercropping is a real opportunity for sustainable intensification of agriculture. As usual with researchers, they also conclude that more research is needed if this system is to be implemented successfully!

Intercropping Cereals and Grain Legumes

This cropping system is practised on many farms in Switzerland, especially organic farms. In most cases, winter peas or field beans are combined with cereals for producing stock feed (Clerc et al. 2015). Winter peas with barley and field beans with oats have proved good partners; the cereals act as a support for the legumes which, otherwise, have a tendency to lodge. The recommended quantities of seed are 80% of the normal amount of seed for peas and 40% of the normal amount of barley.

Cereal/Lupin Mixtures

Lupins are undemanding; they thrive even on acid soils. In 2016, in cooperation with the Research Institute of Organic Agriculture, trials were carried out using blue lupin (*Lupinus angustifolius*) with several companion crops. Along with other factors, the land equivalent ratio (LER) was calculated as a yardstick of productivity: this is the ratio of the area under sole cropping to the area under intercropping needed to give equal amount of production at the same management level. It is the sum of the

Table 16.1 Relative yields and land equivalent ratio (LER) of the different mixed crops with blue lupin (variety Boruta), Rümikon, Switzerland 2016

Relative yields and LER					
Crop varieties	Yield (dt/ha)		Relative yield		
	Lupin	Partner	Lupin	Partner	LER
Boruta	18.92		1		1
Boruta/SO 395-12	9.08	26.89	0.48	0.63	1.11
Boruta/SO Buggy	10.00	17.98	0.53	0.45	0.98
Boruta/ST Trado	16.96	5.10	0.90	0.24	1.13
Boruta/WT Arti 8	18.17	6.04	0.96	0.29	1.25
Boruta/red fescue	20.89	0.00	1.10		1.10
Spring oats 395-12		42.86		1	1
Spring oats Buggy		39.84		1	1
Spring triticale Trado		21.53		1	1
Winter triticale Arti 8		21.07		1	1

fractions of the intercropped yields divided by the sole-crop yields (FAO 1985). With one exception, the LER was always greater than 1, so land resources are better used under intercropping than in sole cropping.

It turns out that in these mixtures, the crop variety is crucial: the best results were achieved with a mixture of lupin *Boruta* and the winter triticale variety *Arti 8*, which gave an LER of 1.25 (Table 16.1). Martin-Guay et al. (2017) noted an average LER of 1.3; the poorer average LERs in the Swiss studies might be explained by good crop rotation, organic practice and favourable growing conditions when no major stress situations occurred.

Maize/Beans Mixture

In 2011, the Thünen Institute for Organic Farming, in Germany, carried out initial trials of a maize/bean mixture which commonly yielded greater crude protein contents than maize silage grown alone (Fischer and Böhm 2017). Our own trials under organic conditions in 2014–2015 showed that the technique works well (Fig. 16.2). Maize was sown at a density of 6–7 seeds/m^2 (and in the control, with maize alone, 10–11 seeds/m^2) and beans (*Phaseolus vulgaris*, *P. coccineus*) at a density of 7–8 seeds/m^2. The maize was sown first, hoed when it reached the four-leaf stage, then beans were sown next to maize rows.

Maize alone yielded 200.6 dt/ha dry matter (DM); the maize component in the mixed batch yielded 178 dtDM/ha so the control produced an additional 13% yield of maize but the difference is not statistically significant. The total dry matter yield in the mixture (maize 178 dt/ha plus beans 16.1 dt/ha) produced an average of

Fig. 16.2 Maize with common bean variety Blauhilde (left) and runner bean Scarlet Emperor (right)

194.1 dtDM/ha (3% less than the control but, again, not a statistically significant difference) (Fig. 16.3).

Ultimately, what counts are the calories and protein produced. On average across all bean varieties, there was no difference in the carbohydrate yield per hectare. However, the variations between varieties were considerable: the mixture containing the bean variety *Trebona* produced only 87% of the yield of maize alone, whereas the mixture with variety *Grünes Posthörnli* achieved 108% of maize grown as a sole

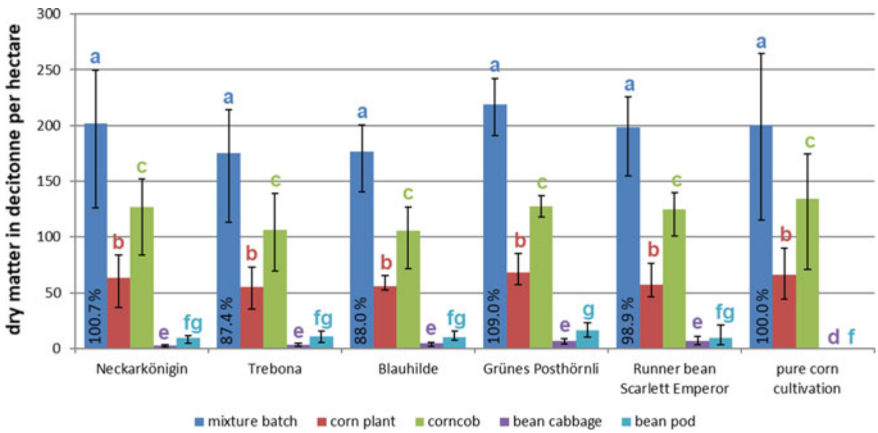

Fig. 16.3 Dry matter yields of the mixture and the individual components in dt/ha, field trial in 2014 in Uettligen, Switzerland. Superscripts mark statistically significant differences ($p < 0.05$)

Table 16.2 Crude protein yield in dt dry matter (DM)/ha of pure corn and the mixture divided into the individual components in dtDM/ha and %. Field trial in Uettligen, Switzerland, 2014

	Crude protein in dtDM/ha Total	Corn plant dtDM/ha (part in %)	Corncob dtDM/ha (part in %)	Bean-herb dtDM/ha (part in %)	Bean-pod dtDM/ha (part in %)
Common bean *Neckarkönigin*	15.7	3.6 (23.0)	10.3 (65.4)	0.3 (2.1)	1.5 (9.5)
Common bean *Trebona*	13.6	3.0 (21.9)	8.6 (63.2)	0.3 (1.9)	1.8 (12.9)
Common bean *Blauhilde*	14.5	3.0 (20.4)	9.4 (64.9)	0.4 (2.7)	1.7 (11.9)
Common bean *Grünes Posthörnli*	18.3	3.7 (20.5)	11.1 (60.7)	0.7 (3.7)	2.7 (15.0)
Runner bean *Scarlet Emperor*	15.0	3.2 (21.3)	9.6 (64.0)	0.8 (5.2)	1.4 (9.5)
Average beans	**15.4**	**3.3 (21.4)**	**9.8 (63.7)**	**0.5 (3.1)**	**1.8 (11.8)**
Pure cultivation maize	**14.8**	**3.9 (26.5)**	**10.9 (73.5)**		

crop. Similarly, there was on average no difference in crude protein yield but there were considerable variations between varieties; the mixture with bean variety *Grünes Posthörnli* produced the highest crude protein yield of 18.3 dtDM/ha—24% more than maize grown alone (Table 16.2).

The trial was repeated in 2015, with similar results. In 2018, a further trial was planted using popcorn, polenta, two varieties of climbing bean and one scarlet runner bean. Unfortunately, the weather was so dry in Switzerland that the beans died from lack of water.

Under-Sowing

The main purpose of under-sowing is to avoid the need for herbicides. It also arrests soil erosion and, if the under-sown crop is a legume, it fixes nitrogen. First and foremost, the successive crop can benefit from the fixed nitrogen bound in soil organic matter but, in the case of oilseed rape, the rape itself can benefit from being under-sown with a crop including frost-sensitive legumes. The presence of autumn-sown, frost-sensitive legumes results in 20–40 kgN/ha higher nitrogen uptake compared with a rape crop without under-sowing (Lorin et al. 2016). Our own trials with four different under-sown mixtures were carried out over four years (Table 16.3).

Table 16.3 Under-sowing trial of oilseed rape, Zollikofen, Switzerland 2015–19

	kg/ha											kg/ha
	Egyptian clover *Trifolium alexandrinum*	Persian clover *Trifolium resupinatum*	Fenugreek *Trigonella foenum-graecum*	Niger seed (ramtil) *Guizotia abyssiniea*	Buckwheat *Fagopyrum esculentum*	Common flax *Linum usitatissimum*	Lentil *Lens culinaris*	Common vetch *Vicia sativa*	Grass pea (chickling pea) *Lathyrus sativus*	Lacy phacelia *Phacelia tanacetifolia*	Subterranean clover *Trifolium subterraneum*	Total
Colza fix	3			2	7		7	5	6			30
S2			6		5	4	12		7			34
Ra1		4	3							3	8	18
Ra2		3	3	3					3		6	18
H	Control 1 (pre-emergence herbicide treatment)											
0	Control 2 (no weed control, no under-sowing)											

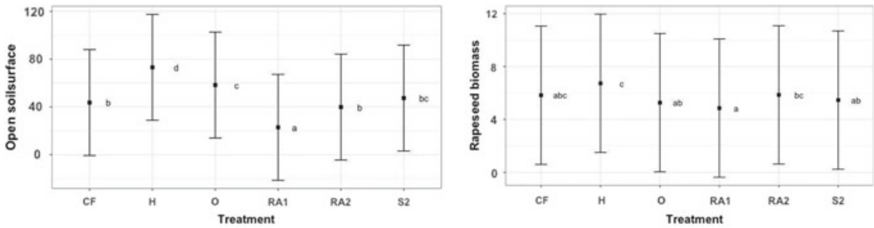

Fig. 16.4 Bare soil surface, %, 30 days after sowing of the oilseed rape (left) and oilseed rape biomass production in the spring (right). Control of herbicide (H) and zero (O) in comparison with several under-sown mixtures. Results from 4 experimental years. Superscripts mark statistically significant differences ($p < 0.05$)

The under-sown crops achieved varied coverage 30 days after sowing the rape (Fig. 16.4, left). In the best cases, weed suppression is almost as good as with herbicide treatment. However, weed suppression alone is not conclusive; the rape must not suffer from direct competition with the under-sown crop. A biomass survey in spring, shortly before flowering, is a good indicator of yield; it shows that the best mixtures (RA2) achieve practically the same biomass as the procedure with herbicide treatment (Fig. 16.4, right). Therefore, in the case of oilseed rape, we may assume that under-sowing can replace herbicide treatment without loss—but it only works if there are no problem weeds, such as thistles, and if the field is cleaned, e.g. by shallow stubble cultivation after harvesting the preceding crop.

Under-sowing has other benefits:

- It prevents soil erosion at the rape's seedling stage
- The above-ground biomass of the under-sown plants contains 4-54 kgN/ha, depending on the mixture and year
- The under-crop deters cabbage stem flea beetle (*Psylliodes chrysocephala*). Significantly fewer flea beetle larvae were counted in spring in the fields with undercrops (Fig. 16.5).

Green Manures

In arable farming, green manures play a key role in conserving and converting nutrients. A fast-growing cover crop following the harvest protects the soil from erosion and leaching of nutrients and improves soil structure and water infiltration. Legumes offer additional potential as green manures because their symbiosis with rhizobia adds nitrogen. Our own study evaluated 19 legume species grown as cover crops in Switzerland. Field experiments in 2010 and 2011 were set up to monitor the biomass production and nitrogen content of 19 legumes and two non-legumes. The proportion of nitrogen derived from atmospheric N_2 (%Ndfa) was assessed using the ^{15}N natural abundance method. In parallel, a pot experiment was set up to determine the species-specific *B* values necessary to apply this method.

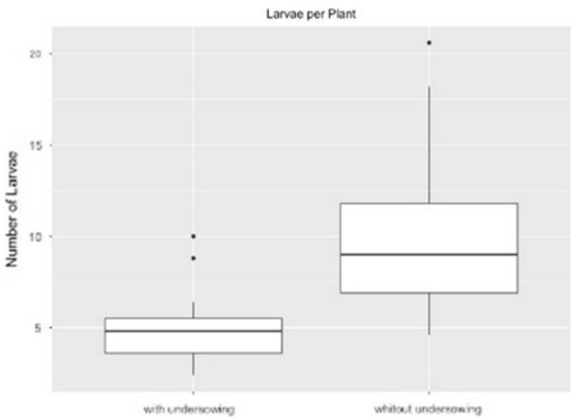

Fig. 16.5 Number of cabbage stem flea beetle larvae per rape plant in spring 2019 in the procedures with and without under-sowing. With under-sowing, lower numbers of larvae are statistically significant (*p* 0.0003865)

Some species produced a goodly amount of biomass in three months, up to 6.86 tDM/ha for *Vicia faba*. Five species, *Lathyrus sativus*, *Pisum sativum*, *Vicia sativa*, *V. villosa* and *V. faba*, acquired more than 100 kgN/ha through biological fixation; substantial amounts of nitrogen were also assimilated from the soil. Values of %Ndfa were very variable between and within species, ranging from zero to almost 100%. Some legumes accumulated substantial amounts of N, even in a short growing period, and could play a valuable role in fixing renewable nitrogen in crop rotations (Büchi et al. 2015); that is why our current trials are focussing on green manure mixtures with a high proportion of legumes. Green manure mixtures offer several advantages over sole crops: by reliable emergence, they optimise the use of root space, nutrients, water and light; winter-grown frost-sensitive green manures provide successful live mulching of spring crops; and the mulched soil stays workable in spring and warms up quickly if the frozen green manure has a light colour, such as peas.

Contract Farming—Solidarity Agriculture

Consumers have become distanced from the production of their food. They no longer understand what is needed to produce enough healthy food in an environmentally friendly way; so, this year, we launched a small project called *My Vegetables*, in which the farmer provides land, equipment, tillage, sowing and planting fruit and vegetables and know-how for maintenance work and harvest (WhatsApp, field surveys). The crops were sown/planted in a few rows but over a length of 200 m for efficiency (Fig. 16.6). The consumer (or the consumer family) rents 5 or 10 m of the whole width of the strip (so has different vegetables and fruits throughout the season) and is responsible for maintenance (e.g. weeding) and harvest.

We have found that the consumer learns what it takes to produce food, learns to appreciate it again, re-thinks its quality standards and is willing to pay a fair price.

Fig. 16.6 Contract-solidarity agriculture to bring the consumer back closer to food production. *My Vegetables* project at Münsingen, Switzerland 2019

Conclusion

Agriculture and the food industry face severe challenges. As things stand, global agriculture is making perilous trade-offs between production of food, stock feed and fuel on one hand and, on the other hand, ecosystem services, ecological stability and our own well-being. Adoption of ecological elements like integrated production and intercropping within mainstream farming systems could be one response; and another could be up-scaling ecological farming systems such as strict organic farming and permaculture/agroforestry.

Governments must play their part in promoting such approaches. We, the consumers, must also be prepared to contribute by moderate consumption with a higher proportion of plant-based foods, and by avoiding food waste (e.g. a return to the concept of nose-to-tail eating), quality requirements should also be reconsidered. Not least, we must be prepared to pay a fair price for our food (Allan and Dent 2021). All might be achieved if the consumer is brought back closer to farming, so as to foster understanding of food production. Models such as contract farming and solidarity agriculture can help this to happen.

The challenge for agricultural research is to develop more productive, more resource-efficient farming systems suited to local and regional circumstances.

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