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This is the author's manuscript

Original Citation:

Availability:

This version is available <http://hdl.handle.net/2318/157708> since 2016-07-04T15:42:57Z

Published version:

DOI:10.4081/ija.2015.643

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UNIVERSITÀ DEGLI STUDI DI TORINO

This is the accepted version of the following article: Zavattaro, L., Costamagna, C., Grignani, C., Bechini, L., Spiegel, A., Lehtinen, T., Guzmán, G., Krüger, J., D'Hose, T., Pecio, A., van Evert, F.K., ten Berge, H.F.M., 2015. Long-term effects of best management practices on crop yield and nitrogen surplus. *Italian Journal of Agronomy* 10, 47–50. doi:10.4081/ija.2015.643,

which has been published in final form at
http://www.agronomy.it/index.php/agro/article/download/ija.2015.643/pdf_13

1 **Long-term effects of best management practices on crop yield and nitrogen surplus**

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14

15 **Abstract**

16 Inherent in the concept of Good Agricultural Practice (BMP) is that it improves resource use
17 efficiency, mitigates environmental impact or increases farm profitability. However, it is usually
18 impossible to achieve all the objectives, and trade-offs need to be accepted, such as a reduction in
19 productivity together with a reduction in costs or an increase of soil organic matter. A European
20 FP7 project, Catch-C (www.catch.eu) analyzes the effects that different management practices have
21 on productivity, mitigation of climate change and chemical, physical and biological soil fertility,
22 based on simple indicators. Such indicators were collected from international literature, national
23 scientific or technical journals, or grey literature that dealt with long-term field trials in Europe. We
24 collected and analyzed data from more than 350 experiments.

25 This paper presents the overall results of the effects of a series of BMP have on crop productivity,
26 soil nitrogen (N) uptake, N use efficiency end N balance. Important interactions with soil and
27 climate types, crop and duration of the experiment were noticed for most BMPs. Rotations, also
28 including double cropping, were among practices with more positive effects of productivity and N
29 indicators. A slight reduction of yield counteracted benefits to soil quality and to climate change
30 mitigation of minimum and no tillage, and of organic fertilizers.

31

32 **Keywords**

33 Best Management Practice, climate change, cropping system, nitrogen, yield

34

35

36 **Introduction**

37 Soil management practices such as crop rotation, adoption of cover crops and green manuring, crop
38 residue incorporation and substitution of mineral with organic fertilizers may maintain soil fertility
39 and ensure adequate crop productivity and efficient use of resources.

40 The effects of agricultural practices can only be assessed properly in long-term experiments (LTEs),
41 where small changes can accumulate over the years until they become detectable, and interaction
42 with meteorological variability can be assessed (Johnston, 1994).

43 In the context of the European project CATCH-C (www.catch-c.eu), we performed a review of
44 European LTEs on arable crops to verify the hypothesis that the above mentioned practices are not
45 only effective in improving the soil quality, but also in maintaining high yields and quality. Here,
46 the results related to crop productivity and nitrogen (N) use are presented.

47

48 **Materials and Methods**

49 We analyzed multi-year averages of crop yields, N uptake and field N surplus (difference between
50 N supply and N removal) from 106 LTEs across Europe. Our literature review included scientific
51 and technical papers, and grey literature, both in English and in national languages, yielding a total
52 of 115 papers.

53 Agricultural practices considered were crop rotation; catch/cover crops (either harvested or
54 incorporated in the soil as green manure); no-tillage and minimum tillage; organic fertilization with
55 compost, farmyard manure, or bovine slurry; and crop residue incorporation into the soil.

56 Yields obtained using each practice were divided by those obtained when the practice was not
57 adopted (i.e. reference treatment): rotation vs. monoculture, catch crops or green manure vs. bare
58 soil; no-tillage and minimum tillage vs. conventional tillage; organic fertilization vs. mineral
59 fertilization at the same nitrogen input; crop residue incorporation vs. removal. The comparisons
60 were made by ensuring that all factors different other than the one tested were equal in the two
61 treatments under comparison (e.g. two tillage treatments were compared within the same rotation).

62 The obtained indicator is called the response ratio (RR), and it is greater than one when the practice
63 increases yield. Nitrogen uptake and N use efficiency (NUE) were also analyzed using RR, while N

64 surplus was examined using the difference between the practice and reference treatment (DIFF). A
65 negative DIFF indicates a reduction in surplus when the practice is adopted.

66 A one-sample t-test (2 tails) was used to identify which RR means were significantly different from
67 1, and which DIFF means were significantly different from 0 ($P < 0.05$).

68 A multiple linear model was performed using climate type (Metzger et al., 2005), soil type and
69 duration of practice (4 levels each), and crop type (12 levels) as nominal factors, to evaluate which
70 conditions mostly affected the performance of each practice (Zavattaro et al., 2014).

71

72 **Results**

73

74 Results are reported in Figure 1. Further details can be found in Zavattaro et al., 2014.

75 In more than 80% of the cases, the yield of a crop grown in a rotation was larger than the yield of
76 the same crop grown in a monoculture, and the average increase in yield was 5%. The largest
77 differences were found in the Western European climate, on sand or loam soils, with wheat or grain
78 maize, and in long-lasting experiments (10-20 years). Conversely, legume or grass leys and minor
79 small grain cereals (such as rye or triticale), and clayey soils represented unfavorable conditions for
80 a rotation. However, while the productivity of a specific crop could be increased in a rotation, the
81 dry matter production of the entire rotation was generally lower than that of the single crop grown
82 in monoculture. Crop N uptake was also generally increased and N surplus was reduced in a
83 rotation compared to a monoculture.

84

85 In 60% of the cases, the use of a harvested leguminous or non-leguminous catch/cover crop resulted
86 in a yield increase of the main crop. Best results were obtained in Eastern Europe, in soils other than
87 silty, crops such as barley, maize or minor cereals, and in long-lasting experiments. Nitrogen uptake
88 was also increased in 80% of cases, and consequently N surplus was reduced. Little or no overall
89 effect of incorporated green manure on yield and N uptake was observed, in all pedo-climatic

90 conditions explored. The N uptake and N surplus of the main crop was reported only in two cases in
91 northern Europe, with opposite trends: positive for barley, negative for wheat. None of the factors
92 considered in the multiple linear model was significant.

93
94 No-tillage has been widely studied in Europe, especially in southern and western countries. Most of
95 LTEs were started in the '80s, and published data are therefore referred to several years of
96 application. Wheat and barley are the most frequent tested crops. On average we observed a yield
97 reduction of 4% in no-tillage compared to conventional tillage, although the change ranged from -
98 32% to +31%, following a normal distribution. Silty soils performed the best. Nitrogen uptake was
99 lower in 73% of cases, resulting in an average non-significant reduction by 5%. Nitrogen surplus
100 was enhanced up to +43 kg N ha⁻¹, or reduced up to -88 kg N ha⁻¹, depending on the crop N
101 removal. The RR of NUE showed an overall average tendency to increase by about 5%.

102
103 We classified as 'minimum tillage' a variety of experimental treatments carried out with
104 heterogeneous machinery. What all management practices had in common was that they did not
105 imply an inversion of the soil and that tillage was performed at a shallower depth than normally
106 adopted in ploughing in the same area. We observed RR of 0.97 (significantly different from 1)
107 between yields under minimum and conventional tillage; however, it ranged from +52 to -46%, and
108 65% of the values were smaller than 1. Most of cases lay between -10 and +5%. Nitrogen uptake
109 and efficiency were more sensitive than yield: they were significantly reduced in 92% of cases and
110 by 9% on average, thus evidencing that N availability was reduced with minimum tillage. Nitrogen
111 surplus was consequently increased by 13 kg N ha⁻¹ on average. None of the factors considered
112 resulted to affect the performance of this technique on yield, whereas N uptake and N surplus were
113 significantly affected by climate (in particular, N uptake was increased and N surplus was reduced
114 in Western Europe Atlantic climate).

115

116 All kinds of composts (plant-based, biowaste or sludge materials) were pooled in this analysis, for a
117 total of 21 experiments, mainly located in Central Europe. When compared to a similar N
118 fertilization level supplied using mineral fertilizers, compost additions showed a good supplying
119 capacity of nutrients, as yield RR had a mean of 0.95 (not significantly different from 1). More than
120 70% of cases lay in the range +6 to -6%; in one case in Scandinavia, with maize on a clay soil, the
121 performance was remarkably high (+67% of yield). Best results with compost were obtained when
122 vegetables (leeks, Brussels sprouts) and peas were cropped, while grain maize and barley yield was
123 notably depressed. As several authors report (e.g. Alluvione et al., 2013), compost can release
124 nutrients slowly and immobilization can occur in the first years of supply. Therefore, it is not
125 surprising that good results with this fertilization practice were observed only after some years of
126 repeated additions (>5 years).

127

128 The 60 experiments on farmyard manure used for this study were mainly located in Eastern
129 European (Pannonian) climatic conditions and medium or coarse-textured soils. Especially, long-
130 term experiments which lasted for more than 20 years were represented. On average, a significant
131 reduction in yield by 6% was observed. The variability around the mean was notable; 52% of RRs
132 were smaller than 1. Results obtained in northern Europe on fodder maize were extremely positive,
133 although the absolute yield was rather low (<5.5 t ha⁻¹ of aboveground DM in the manured plots).
134 Conversely, eight cases in Western Europe with Atlantic climate showed a reduction in marketable
135 production. Coarse-textured soils, where mineralization is enhanced, created more favourable
136 condition for manured treatments. All tested crops responded to manure application in a similar
137 way, according to the statistical test. However, a tendency to benefit more of the N mineralization
138 of organic fertilizers was observed in summer crops, probably because they can better exploit N
139 released from mineralization of manure, if compared with crops whose maximum requirements are
140 asynchronous with the organic fertilizer mineralization curve.

141

142 Bovine slurry was tested in 37 experiments that were located mainly in Eastern and Southern
143 Europe. Most experiments lasted for more than 10 years. Tested crops were mainly forages, and
144 coarse-textured soils were the most represented. In these conditions, a rapid mineralization led to a
145 fast release of N in the soil, similar to that of mineral fertilizers (RR not significantly different from
146 1). Values of the yield RR of slurry showed a normal distribution around a mean of 0.98, ranging
147 from 0.52 to 1.58, and greater than 1 in 46% of cases. Therefore, bovine slurry performed even
148 better than solid manure. On the other hand, N uptake (n=11) was 8% lower (significantly different
149 from 1) than in treatments that received mineral fertilizers.

150 Generally, the performance of all organic fertilizers depended on the soil type (best results in
151 coarse-textured soils), climate (the colder, the better) and duration of practice (better results in
152 experiments lasting for more than 5-10 years).

153 In some of the experiments, crop residues acted as a source of nutrients or of stable organic matter,
154 which improved soil physical, chemical, biological and hydraulic characteristics. Incorporation of
155 residues caused an increase in SOC content of about 7% in the same dataset (Lehtinen et al., 2014).
156 However, in other cases straw immobilized N or caused technical difficulties at sowing. The overall
157 mean RR of incorporating residues was significantly different from 1 and negative (-7%), although
158 49% of the values were greater than 1. The maximum value was +16%. Minimum values
159 (RR<0.55) came from two experiments in Slovenia. Residue incorporation was detrimental to crop
160 yield especially in badly structured silty soils, in all crops. Nitrogen indicators were too limited to
161 be representative and were recorded only in continental climate. A slight reduction in N uptake was
162 observed; conversely, the overall N surplus was decreased and NUE was increased by 36%.

163

164 **Conclusions**

165 The indicator-based evaluation of agricultural management practices showed positive and negative
166 effects. Productivity was enhanced when adopting rotation and cover crops. A slight reduction of

167 yield counteracted the benefits to soil quality and to climate change mitigation of minimum and no
168 tillage, and of organic fertilizers. The most important single factor influencing the effect of
169 management practices was the climate type.

170

171

172 **Acknowledgements**

173 This study was part of the European CATCH-C project that is funded within the 7th Framework
174 Programme (Grant Agreement No. 289782).

175

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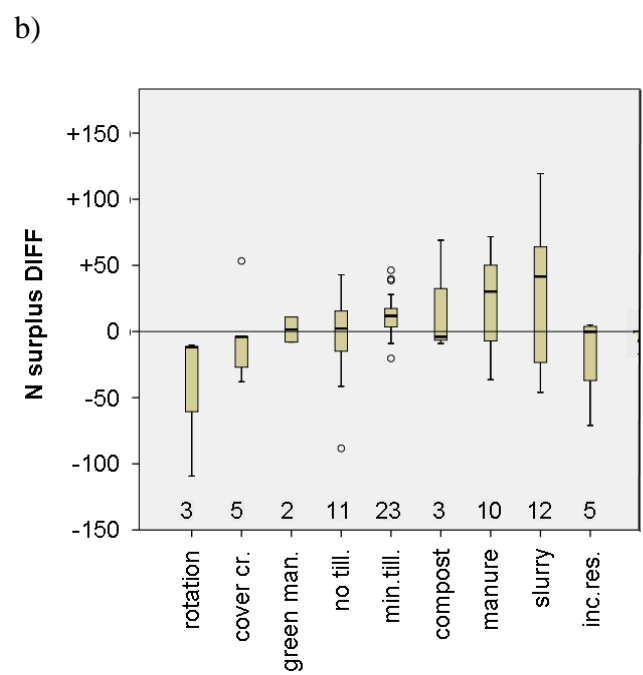
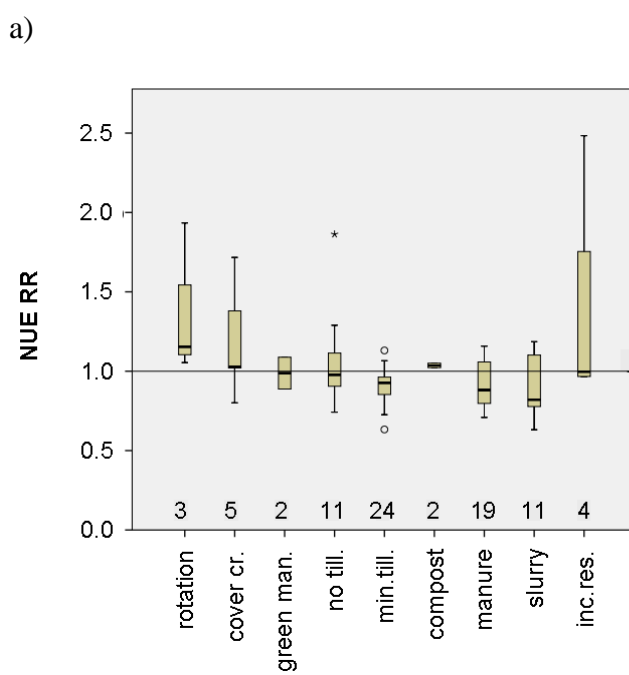
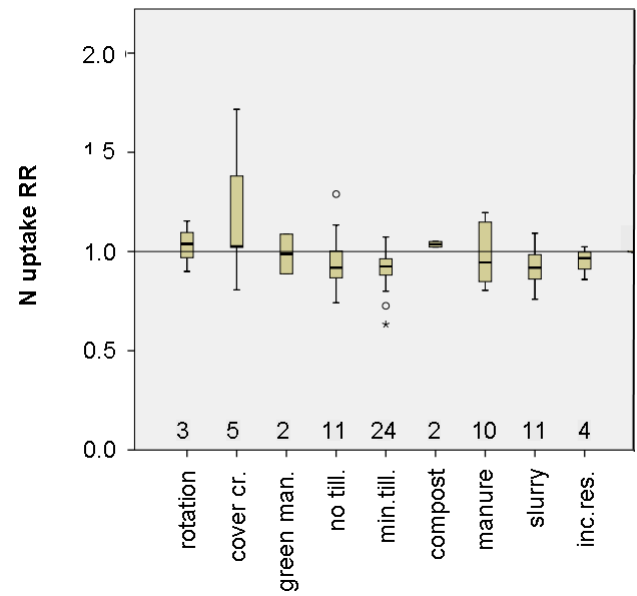
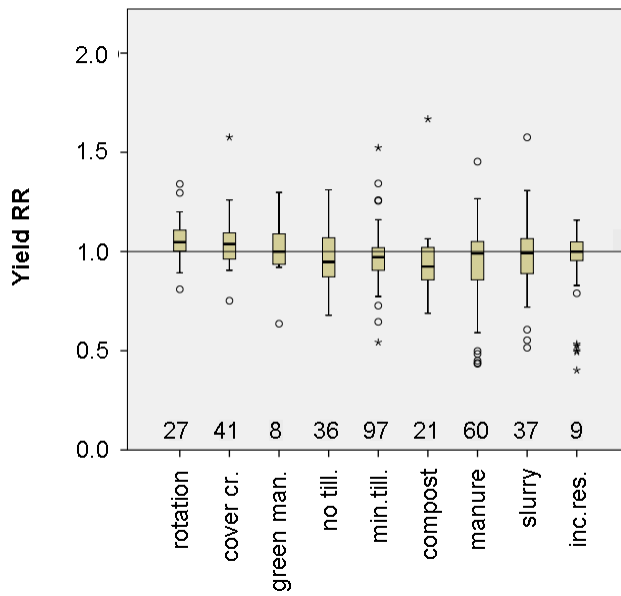
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193 Fig. 1. Boxplot graphs of a) yield RR, b) N uptake RR, c) NUE RR and d) N surplus DIFF obtained
 194 adopting improved management practices compared to standard practices. Numbers indicate the
 195 number of studies considered for each practice. Abbreviations: RR, response ratio; DIFF,
 196 difference between practice and reference treatment; cover cr, catch/cover crops; green man,
 197 manure; no till., no tillage; min. till., minimum tillage; inc. res., incorporation of crop residues.
 198



c)

d)

