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Concept and effects of a multi-purpose grassed waterway

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Abstract. The concept and the effects of a multi-purpose grassed waterway (GWW) were investigated over an eight year period. A GWW, half of it seeded, the remainder left to natural succession, and an intensive soil consevation system in the fields nearby were established in an agricultural watershed (13.7 ha). This combination minimized the maintenance in the GWW without sward damaging sedimentation. In consequence the GWW, as well as providing safe drainage for surface runoff, also served additional ecological roles. During the experiment it reduced runoff and sediment delivery from the watershed by 39% and 82%, respectively. Moreover it improved biodiversity on the research farm and acted as a refuge for beneficial organisms. Soil mineral nitrogen content decreased by 84% after the installation of the GWW, indicating that although infiltration into the GWW was rapid, the risk of groundwater contamination from leached nitrate was diminished. The agricultural assets and drawbacks of establishing GWWs were also studied. We showed that the economic returns were more likely to be improved than reduced. Creating the GWW by natural succession had some advantages compared to seeding with grass.

Keywords: Erosion control, vegetated waterways, soil conservation, runoff, nitrogen, leaching, pollution control

INTRODUCTION

Grassed waterways (GWWs) are a common erosion control measure in Northern American agriculture (Ripley *et al.* 1975; Atkins & Coyle 1977; Chow *et al.* 1999). Broad, shallow channels (natural or constructed) with a grass cover are used to drain surface runoff from farmland without gullying along the base of the drainage way (thalweg). Commonly a selection of fast growing local grasses is used, which build a dense sward and an intensive root network (Atkins & Coyle 1977). To keep GWWs effective, proper maintenance is necessary: erosion damage after large runoff events must be immediately eliminated; damage to swards from sediment cover should be prevented by frequent mowing (Wilson 1967) in order to maintain hydraulic roughness in the GWW.

In contrast to North America GWWs are not widely used in Europe. This can be attributed to differences in soil properties, climatic conditions, land ownership, field layout and cropping practices. To examine the benefits in European farming practice, a GWW was established in 1993 within the framework of the Munich Research Alliance on Agro-Ecosystems (FAM) (Auerswald *et al.* 2000) and studied over an eight year period. The GWW differed from the common North American practice in two ways:

(1) maintenance in the GWW was reduced by combining it with intensive soil conservation measures in the adjacent fields; and
(2) the layout was not primarily optimised to fulfil its drainage function because it was also introduced to improve the layout of several neighbouring fields. Hence the width of the GWW ranged from 10 m to 50 m, a width that is unnecessary for satisfactory drainage.

A GWW with minimal maintenance provides several ecological benefits. It may reduce runoff, sediments and harmful substances leaving an agricultural watershed, it may reduce peak runoff discharges and prevent muddy floods, and it may also improve biodiversity in intensively used agricultural areas and act as pathway for linking habitats. As Henry *et al.* (1999) suggested for the planning of conservation corridors in USA farmlands, GWWs should be taken into account as useful linear landscape structures.

This multi-functionality should be well suited for European conditions where intensive agriculture and dense population pressures, accentuate 'off-site' hazards resulting from erosion.

The aim of the present study was to investigate additional ecological advantages and possible disadvantages, and also to evaluate the technical and economic benefits and drawbacks of multi-purpose GWWs.

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MATERIAL AND METHODS

The test site

The test site was part of the FAM experimental farm, which was located in the Tertiary hills, an important agricultural landscape of Central Europe. The main land use principle of the FAM research alliance was to use soil and site specifically to match land capability and land use. To reach this goal, fields were redesigned, e.g. steep erosion prone sandy slopes were taken out of arable use and pastures were established, and smaller fields with a more convenient layout were created in autumn 1992. The main principle of cropping was that soil cover should be maintained as long as possible by crop or intercrop plants or at least by their residues (Auerswald *et al.* 2000). On the test site, integrated farming was adopted with a crop rotation consisting of potato, winter wheat, maize and winter wheat. This rotation allowed planting of a cover crop (mustard) before each row crop. Maize was planted directly into the winter-killed mustard. Potatoes were planted in ridges formed before sowing the mustard which provided winter-killed cover. Reduced tillage allowed the residues of maize and winter wheat to provide a mulch cover and lessened soil compaction. Only wide low-pressure tyres were used on all machinery to further reduce soil compaction and to avoid the development of wheel-track depressions, which usually encourage runoff (Auerswald *et al.* 2000).

The test site consisted of two small adjacent watersheds one 13.7 ha the other 9.4 ha (Figure 1), with mean slopes of 8.9% and 7.2% respectively (Table 1). Predominant soils are loamy or silty loamy Inceptisols. In addition to the protection against sheet erosion in the fields, rill or gully erosion along the thalweg was prevented in both watersheds by small retention ponds ($220\,m^3$–$490\,m^3$) with underground-pipe outlets (Figure 1), which dampened peak runoff and retained sediment (Weigand *et al.* 1995). In the southern watershed a GWW, 650 m long and 10 m to 50 m wide, with an average slope along the thalweg of 4.7%, was also established in 1993. Its size resulted from the specific landscape characteristic and the intention to create fields with a multiple width of the current agricultural machinery. This GWW was divided into two parts: an upper (western) part where natural succession occurred (Figure 2) and a lower (eastern) part where grass was sown and cut annually at the end of July (Figure 3) with the cut grass left as a mulch on the surface.

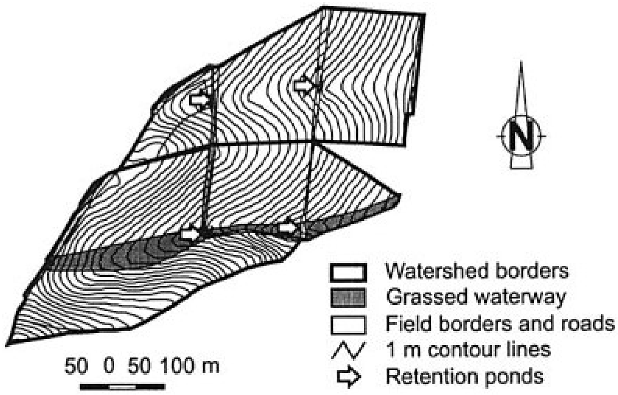

Figure 1. Location of the two paired watersheds, the southern with a grassed waterway, the northern without; flow direction from west to east.

Figure 2. Upper (western) part of the grassed waterway after eight years of natural succession.

Table 1. Properties of the two adjacent watersheds with and without grassed waterway; LS and K factors according to the USLE.

Properties		Watershed with grassed waterway	Watershed without grassed waterway
Area	(ha)	13.7	9.4
Arable land	(%)	81	87
Grassland	(%)	0	0
Set-aside area	(%)	12	18
Field roads	(%)	1.3	1.3
No. of fields		4	3
Crop rotation		ww-m-ww-p	ww-m-ww-p
Mean slope	(%)	8.9	7.2
Mean LS factor		3.6	1.6
Mean K factor		0.40	0.39
No. of retention ponds		2	2

ww = winter wheat, m = maize, p = potatoes

Measuring methods

Rill and gully erosion along the thalwegs was investigated by frequent field observations. Its extent was estimated by measuring the length and the cross section of gullies that formed during the establishment of the GWW. To evaluate the protection efficiency, these observations were compared with the damage created by a large thunderstorm in August 1992 and with results from modelling erosion and deposition of the site before establishing the GWW. The soil loss from ephemeral gullies and larger rills during the August thunderstorm was evaluated by determining the length of gullies and rills from aerial photos (scale 1:10 000) and measuring their cross-sections in 25 m steps along the gullies and along transects taken perpendicular to the rills. Eroded volume was converted to eroded mass using measured bulk densities. The GIS based model used (Mitasova *et al.* 1996) calculated an erosion and deposition index in a 2 m by 2 m grid. It required a high-resolution digital elevation model and a detailed K factor (soil erodibility factor of the

Figure 3. Lower (eastern) part of the grassed waterway, which was seeded and cut and mulched annually; in the middle of the picture an elevated farm road creates a small retention pond, which is drained by an underground-pipe outlet (white tube).

Universal Soil Loss Equation (ULSE)) map of the watershed.

The effectiveness of the GWW in reducing runoff and sediment delivery from the adjacent fields was studied by the comparison of the paired watersheds. In both watersheds runoff and sediment delivery were measured continuously beginning in January 1994. The measuring system and results were described in detail by Fiener & Auerswald (2003). Here we focus only on the overall effect. The comparison of the paired watersheds is based on their similar soil characteristics, soil conservation measures, cropping system and the identical crop rotation (Table 1). Hence, differences in sediment delivery per unit area can be expected due to the GWW, the different location of the small retention ponds and the topography. The effects of the retention ponds, which had a sediment trapping efficiency of about 56% (Fiener & Auerswald 2003), was taken into account when calculating the sediment delivery from both watersheds. We use the term sediment delivery for the sum of measured sediment transport across the lower field edge plus sediment deposition in the ponds above the field edge. The differences in topography can be evaluated with the LS factor, which accounts for slope and slope length effects on erosion (Wischmeier & Smith 1978). The LS factor differed by a ratio of 2.3:1 between the watershed with and without the GWW. Due to the extensive validation of the USLE that has been carried out in this landscape during the last two decades (e.g. Schwertmann *et al.* 1987), it was assumed that the USLE is suitable and that the LS factor accounts accurately for the difference in topography (Auerswald 1986). Therefore it was used to adjust the measured soil deliveries.

As one of the intentions of the GWW was to allow runoff from the adjacent fields to infiltrate, it may have an impact on groundwater quality and recharge. For this reason mineral nitrogen (N_{min}) was frequently measured before and after the installation of the GWW in its upper natural succession section and for comparison in the adjacent fields. Measurements were made to a depth of 0.9 m following standard procedures. N_{min} is the sum of nitrate and ammonium nitrogen. Ammonium remained close or below the detection limit after the installation of the GWW and the management conversion in 1992, so it was not measured after 1993. Water holding capacity needed for the interpretation of the data was taken from Sinowski *et al.* (1997).

To evaluate the effects of the GWW on biodiversity, several studies have been carried out: the vegetation in the GWW was evaluated in May 2001, eight years after its establishment on former arable land, using a relevé survey after Braun-Blanquet on nine 5 m by 5 m wide plots. To evaluate the reactions of soil organisms (protozoa, nematodes, collembola, earthworms and epigeal predators) on former arable land, all set-aside areas were sampled and analysed to provide true replicates instead of repeated sampling at the same location. Biotic inventories of set-aside areas will depend largely on the species in the nearby land and for the first years also on the species inherited from previous land use. Including all set-aside areas into the analysis enabled a more general assessment of biological effects under a wider range of conditions than are found at a single GWW. The methods of sampling and further data analysis are given by Mebes & Filser (1997) and Filser *et al.* (1996). The effects of set-aside areas on the spread of spiders and grasshoppers were evaluated by Agricola *et al.* (1996). Laussmann & Plachter (1998) evaluated trends in the invasion of several not previously present bird species shortly after the reconstruction of the whole research farm. A further bird inventory was carried out for the present study in 2001.

Technical and economical benefits and drawbacks could be studied because the experimental farm was managed like an ordinary farm but was completely under the control of and recorded by the researchers. The main economic drawback of the GWW was the loss of arable land. Consequently the maximum possible income loss was calculated from the average gross margin of the adjacent fields computed with the MODAM model (Meyer-Aurich *et al.* 2001). The economic balance was estimated according to the possible negative effects of damage by gullying and sedimentation and the positive effects in agricultural practices, e.g. using the GWW as headland, which occurred during eight years of experience with the system.

RESULTS AND DISCUSSION

Ecological effects

Protection from gully erosion. Modelling potential erosion without a GWW showed the highest vulnerability in the watershed along the thalweg, where runoff from the two opposite slopes converges. The computed linear erosion exceeded the total sheet erosion in the watershed.

The risk of gully erosion along the thalweg was also impressively demonstrated by the thunderstorm in August 1992. This event, with a rainfall intensity of up to $160\,mm\,h^{-1}$ and a total rainfall of 60 mm, created an

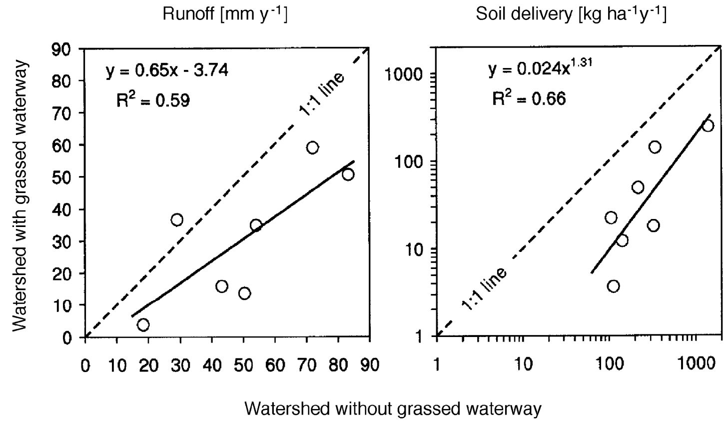

Figure 4. Annual runoff and sediment delivery 1994–2000 of the two paired watersheds; the sediment values have been standardized using the LS factor of the USLE.

Table 2. Thalweg erosion before and after installation of the grassed waterway (GWW); R factors (rain erosivity) calculated from two meteorological stations with tipping-bucket rain gauges both located at a maximum distance of 200 m from the test site.

Thalweg erosion	R factor ($N h^{-1}$)	Soil loss (t)	Soil loss/area of the GWW ($t ha^{-1}$)
Before GWW installation[a]	170	580	354
During installation (1993)			
lower part (seeded)	140	45	78
upper part (succession)	140	0	0
After installation (1994–2000)	420	0	0

[a](Storm August 1992)

ephemeral gully, which was up to several meters wide and 20 cm deep on average along the length of thalweg (Table 2).

Modelling indicated that the potential for linear erosion was similar along the thalweg in the upper and in the lower section of the GWW. The effect of the greater upslope area in the lower GWW was compensated for by a smaller gradient compared to the upper watershed. In contrast to the similar topographical potential for linear erosion, the observed erosion differed greatly during the year of establishment (1993). No linear erosion took place in the upper part of the GWW, which was left to natural succession (Table 2). In the lower part, where grass was sown in 1993, and two retention ponds further dampened peak runoff, gullying occurred. On two occasions the gully had to be refilled by tillage and grass was re-established. A third gully developed in the late summer of 1993 but a dense grass sward developed after this summer event and suppressed further linear erosion. To avoid another vulnerable seedbed, this gully was left open and it persisted for the eight years of observation. It was 30–60 cm wide and about 10 cm deep (half-width depth) incision along the thalweg. The total soil loss during installation of the lower part of the GWW was about 45 t (Table 2). This again indicates the high erosion potential along the thalweg and illustrates the problem arising from a fine seedbed, which is necessary if sown grass is preferred to natural succession.

During the following years no further linear erosion took place. Hence it can be concluded that, except for the problems during the installation phase, the multi-purpose GWW effectively protected the thalweg from linear erosion.

Runoff reduction. The GWW reduced annual runoff in 6 out of 7 observed years (Figure 4, left). In total, runoff was reduced by 39% compared to the paired watershed. This reduction was mainly caused by three processes:

(1) higher infiltration rate in the GWW due to reduced sealing of continuous grass cover compared to more exposed arable soils and decreased soil compaction by reduced wheeling. Modelling indicated that the reduced sealing under grass was especially important during the growing period when infiltration capacity of the dry soils was high but surface runoff could have occurred where arable soils were insufficiently protected from sealing (Schröder 2000);
(2) higher surface storage capacity compared to the thalweg without GWW;
(3) reduction of runoff velocity giving more time for infiltration. This was particularly important for infiltration of runoff occurring after rainfall had ended (Schröder 2000). The effective reduction in runoff velocity is attributed to the greater hydraulic roughness of dense grass compared to crop covered surfaces. This difference in hydraulic roughness is particularly large when there is incomplete vegetation cover in agriculturally used thalwegs. The greater hydraulic roughness provided by greater stem height of grasses, found in several studies (Ree 1949; Temple 1999; Ogunlela & Makanjuola 2000), provides another opportunity for greater efficiency of the multi-purpose GWW compared to the common intensively managed system.

Sediment delivery reduction. The sediment delivery from the watershed with GWW was less in all years (Figure 4 right). In total it reduced sediment delivery by 82% compared to the paired watershed. This was mainly caused by infiltration induced sedimentation and sediment settling due to a

Table 3. Mineral nitrogen (N_{min} kg ha^{-1}, 0–90 cm) in the grassed waterway (GWW) and in the adjacent fields before and after installation of the GWW and management conversion; data from 1991 to 1999.

	Mineral nitrogen	
	grassed waterway	adjacent fields
Before GWW installation (1991–1992)		
Median	39.7	36.2
Median absolute deviation	17.7	8.4
No. of sampling occasions	21	10
After GWW installation (1993–1998)		
Median	6.2	26.4
Median absolute deviation	2.5	22.0
No. of sampling occasions	21	26

reduced transport capacity and a prolonged runoff travel time (Fiener & Auerswald 2003).

In spite of the high sediment trapping efficiency, the vegetation in the waterway was not damaged by sedimentation. In total, the GWW retained 107 t sediment during seven years of examination. On average these 107 t correspond to an annual sedimentation depth of 0.6 mm if a bulk density of 1.5 kg dm^{-3} is assumed. Even if this sedimentation was concentrated only on one tenth of the GWW it was insufficient to cover and kill the vegetation.

Beside these on-site effects, considerable off-site effects of a GWW can be expected but were not examined. It can help to prevent (muddy) floods caused by runoff from arable land, which damage down slope infrastructure and private property and it can protect surface water bodies from harmful substances coming from non-point sources.

Changes in mineral nitrogen. Before installing the GWW, when the whole area was homogeneously cropped with wheat (1991) and barley (1992), the area of the GWW showed a similar median N_{min} to the adjacent fields (Table 3). After the installation and the simultaneous change in field management, N_{min} in the fields adjacent to the GWW decreased by 27% with a rather high temporal variability due to field operations and crop development (Table 3). In the GWW the median N_{min} decreased by 84%. This decrease occurred during the first year and exhibited a low variability (Figure 5). Even if the total N_{min} in the soil below the GWW were leached, an average concentration of 10 ppm NO_3 in the percolating water can be computed from the average amount of N_{min} down to 0.9 m depth and the field capacity of the soil. This is well below potable water standards. Hence a negative impact on groundwater quality due to the high infiltration rates in the GWW is unlikely.

N_{min} in the GWW differed not only in amount but also in depth distribution from that found in the surrounding fields. While on average 50% of the N_{min} of arable fields was found below 30 cm, the mean percentage in the GWW was only 3%. This, again, indicates only small losses to groundwater.

Yield analysis previous to the establishment of the GWW revealed that subsurface flow had contributed a significant amount of water and dissolved nutrients to crop development where the GWW was later installed (Auerswald *et al.* 2001). This caused the highest N_{min} values during the growing period to occur along the thalweg (Hantschel & Stenger 2001). The low nitrate concentration below 30 cm indicates that either the GWW was able to take up this additional nitrate or the change in crop management of the surrounding field had decreased subsurface losses.

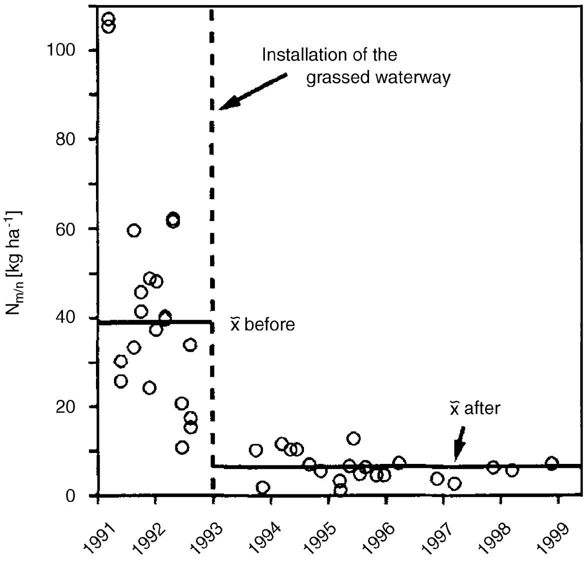

Figure 5. Changes in mineral nitrogen (N_{min}, 0–90 cm) in the grassed waterway after conversion from arable to uncropped farmland

The infiltrating runoff added on average another 159 mm of water to the annual water budget of the GWW. It can be expected that groundwater recharge (normally about 200 mm yr^{-1}) under the GWW increased by approximately the same amount. The combination of increased groundwater recharge on an area with little nitrate may thus create a favourable effect on the nitrate load of the groundwater.

Effects on plant diversity. Even after 8 years the vegetation of the GWW was dominated by a few fast growing species commonly found in agricultural landscapes (e.g. *Agropyron repens, Dactylis glomerata, Urtica dioica*). Annual cutting of the lower part favoured primarily the growth of fast growing grasses (e.g. *Agropyron repens, Dactylis glomerata, Arrhenatherum elatius*). In the upper part (without cutting) some tall herbs (e.g. *Epilobium angustifolium, Galeopsis tetrahit, Galium aparine*) and woody plants (e.g. *Salix* spec., *Rubus* spec., *Sorbus* spec.) invaded. They contributed about 15% and 1%, respectively, to the total cover. The GWW was thus dominated by plants, which can commonly be found in intensively used agricultural landscapes. This was not surprising because the colluvial soils promoted species, which responded to a high nutrient status. Furthermore, the intensively farmed landscape surrounding the farm did not provide seed sources of other species. The slow invasion of other plants, especially shrubs and trees, on the other hand offered the advantage of a low maintenance effort. The annual cutting as practiced on the lower part was not necessary to prevent encroachment of shrubs. Mowing every 10 years seems to be sufficient to suppress woody species.

Effects on faunal diversity. After installing the GWW, which was one part of redesigning the research farm, and after the management conversion on the whole farm, the soil microbial biomass increased in cropped fields by 37% and in the set-aside areas (former fields) by 47% (Filser *et al.* 1996). In the upper part of the GWW (set-aside) the species composition changed and effects on abundance are given in Table 4. In some cases the set-aside areas acted as a refuge for beneficial organisms, e.g. for a spider and several grasshopper species, which temporarily populated the neighbouring fields (Agricola *et al.* 1996). For this function broad linear uncropped areas are of special importance (Agricola *et al.* 1996). Hence, GWWs may be more effective than other set-aside areas due to their linear structure and location between fields.

The GWW may also have supported the incursion of several bird species not previously present on the research farm (Table 5). However, it was difficult to differentiate between the effects due to the various changes in the landscape and in the cropping practices introduced at the same time as the GWW.

Agricultural effects

The GWW occupied 1.6 ha or 10% of the watershed situated on rich colluvial soils. To evaluate its economic effects it has to be appreciated that its size was the result of optimising the layout of the neighbouring fields. Assuming that a width of about 15–20 m would be enough for an efficient multi-purpose GWW, the size would only be 0.6–0.9 ha or 3.5–5.3% of the watershed area. This area is equivalent to an income loss of 410–650 € yr^{-1}, based on the average gross margin of the neighbouring fields (Table 6). The income loss would be considerably reduced by European Union or local government subsidies. For example in Bavaria up to 500 € $ha^{-1}\,yr^{-1}$ would be paid for a multi-purpose GWW on rich colluvial soils, if it is classified as an area serving agroecological benefits in the long-term (Anon 2000).

Control of gullying and sedimentation reduces further the economic loss. The gullying and sedimentation reduce revenue in three ways: crop loss, impeding field management and long-term soil degradation.

Besides preventing loss, a multi-purpose GWW provides further benefits:

(1) it can serve as an occasionally used farm road in dry periods leading to a reduction in the area of fields used for access tracks.
(2) yields in neighbouring fields may improve because a multi-purpose GWW can act as a refuge for beneficial organisms, shown at the test site by Agricola *et al.* (1996). However the GWW might cause an invasion of pests, especially snails, although this was not important during the eight years of observation. Moreover, it is

Table 4. Percentage of sampling occasions with significant differences (Mann-Whitney U-Test) in the abundance of soil organisms in fields and set-aside areas of the FAM research farm; sampling occasions took place in 1994 and 1995; data from Filser *et al.* (1996) and Mebes & Filser (1997).

	No. of sampling occasions	Significantly higher abundance in set-aside areas	Significantly higher abundance in fields	No significant difference
		(%)	(%)	(%)
Protozoa	2			100
Nematode	2	100		
Collembola				
Total	2	50		50
Folsomia quadrioculata	10		50	50
Folsomia manolachei	10	50		50
Isotomurus palustris	10	60		40
Lepidocyrtus cyaneus	10	60		40
Sminthuridae	10	30		70
Lumbricidae	2			100
Epigeal predators	2		50	50

Table 5. Bird inventory on the research farm before landscape redesign (1991+1992), shortly after redesign (1993+1994) and nine years after redesign (2001); data for 1991-1994 from Laussmann & Plachter (1998); 2001 this study.

Species	1991	1992	1993	1994	2001
Emberiza citrinella	x	x	x	x	x
Passer montanus	x	x	x	x	x
Sylvia communis	x	x	x	x	x
Alauda arvensis	x	x	x	x	x
Lanius collurio			x	x	x
Perdix perdix			x	x	x
Coturnix coturnix			x	x	x
Carduelis carduelis	x	x	x	x	x
Acrocephalus palustris					x
Locustella naevia	x		x	x	x
Saxicola rubetra					x

Table 6. Site-specific gross margins per year according to the MODAM model (Meyer-Aurich *et al.* 2001), and (a) calculations of Wechselberger (2000); revenues of winter wheat including 324 ha^{-1} premium paid by the European Union.

		Winter wheat	Maize	Winter wheat	Potatoes	Average over crop rotation
Revenue	(€ ha^{-1})	1062	1442[a]	951	2603	1514
Costs						
Seeds		53	159	53	454	180
Fertilizer		69	89	69	46	68
Plant protective agents		102	100	102	224	132
Machinery costs		259	281	243	446	307
Total		**483**	**629**	**467**	**1170**	**687**
Labour	(h ha^{-1})	7.4	10.1	7.2	31.8	14.1
Labour costs [10 € h^{-1}]	(€)	74	101	72	318	141
Gross margin II	(€ ha^{-1})	506	712	413	1115	686

possible that the GWW indirectly contributed to the dispersal of weed seeds, e.g. from *Cirsium arvense*, because weeds found optimal conditions for colonisation on set-aside areas of the research farm (Mayer 2000).

(3) In the small patterned landscapes typical of many European regions, field borders often follow the thalweg as at the test site. With a GWW at such a field border the headlands of the neighbouring fields become unnecessary because turning can be done on the GWW. Assuming that field operations are commonly carried out in dry soil conditions, the GWW, where the soil structure is more stable than in the neighbouring fields, should not be damaged. Using a GWW as a headland avoids soil compaction in the field and consequently reduces risk of soil erosion and encourages reduced tillage, which in turn improves the protection against sheet erosion. Contour cultivation will become more effective without a headland, which would be tilled up and down slope. This prevents concentrated runoff on an area destabilized by tillage with frequent soil compaction due to turning operations. Moreover if the headland is replaced by a GWW the harvest of row crops like potatoes is easier. Subsoil compaction will also be reduced in the fields and the problem of applying more agrochemicals than necessary on the headland can be avoided.

Summarizing all these effects of a multi-purpose GWW, we can conclude that the cost of the loss of arable land will be partially if not wholly offset by the benefits.

CONCLUSION

In addition to the onsite beneficial effects of GWWs, positive off-site effects, e.g. preventing muddy floods and protecting surface water bodies form harmful substances, can be expected. Together these benefits may help to improve the popular image of agriculture in Europe where intensive agriculture and population pressure create additional burdens and demands on agricultural land.

However, despite the many advantages of GWWs and a long-lasting and intensive effort to communicate our experiences to farmers, the adoption of GWWs is negligible. The main constraint seems to be a deep-rooted belief that the most intensive soil use will yield the highest income, consequently a financial incentive may be helpful. However any such incentive should only be paid at the outset. A long-term subsidy would be counter-productive because it would fortify the belief that soil and water conservation without subsidy is at the expense of income.

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