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Review

Environmental impact assessment of conventional and organic milk production

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Abstract

Organic agriculture addresses the public demand to diminish environmental pollution of agricultural production. Until now, however, only few studies tried to determine the integrated environmental impact of conventional versus organic production using life cycle assessment (LCA). The aim of this article was to review prospects and constraints of LCA as a tool to assess the integrated environmental impact of conventional and organic animal production. This aim was illustrated using results from LCAs in the literature and from a pilot study comparing conventional and organic milk production. This review shows that LCAs of different case studies currently cannot be compared directly. Such a comparison requires further international standardisation of the LCA method. A within-case-study comparison of LCAs of conventional and organic production, however, appeared suitable to gain knowledge and to track down main differences in potential environmental impact. Acidification potential of milk production, for example, is for 78–97% due to volatilisation of ammonia, which is not reduced necessarily by changing from conventional to organic milk production. Eutrophication potential per tonne of milk or per ha of farmland was lower for organic than for conventional milk production due to lower fertiliser application rates. Global warming potential of milk production is for 48–65% due to emission of methane. Organic milk production inherently increases methane emission and, therefore, can reduce global warming potential only by reducing emission of carbon dioxide and nitrous oxide considerably. Organic milk production reduces pesticide use, whereas it increases land use per tonne of milk. Conclusions regarding potential environmental impact of organic versus conventional milk production, however, are based largely on comparison of experimental farms. To show differences in potential environmental impact among various production systems, however, LCAs should be performed at a large number of practical farms for each production system of interest. Application of LCA on practical farms, however, requires in-depth research to understand underlying processes, and to predict, or measure, variation in emissions realised in practice.

Keywords: Conventional; Organic; Milk production; Environmental impact assessment; Life cycle assessment

1. Introduction

Consumers in wealthy countries demand high quality, safe food that is produced with minimal environmental losses, under optimal conditions for animal health and welfare. Organic agriculture ad-

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dresses these public demands, and has the potential to improve the health and welfare status of an animal, and to diminish environmental pollution of agricultural production (Sundrum, 2001).

At present, nutrient balance at the farm level generally is used to assess the environmental impact of agricultural systems (Anonymous, 1999a; Sundrum, 2001). Nutrient balance at the farm level, however, has several problems: it considers only nutrient losses at farm level, and, therefore, excludes nutrient losses during production of farm inputs (i.e., concentrates, artificial fertiliser); it excludes environmental issues unrelated to the N or P farm cycle, such as fossil energy use or emission of greenhouse gasses; and it often ignores N-fixation by leguminous plants, which is the main N-source in organic dairy production. Nutrient balance at the farm level, therefore, is not suitable to compare effectively the environmental impact of conventional and organic production.

One method that has the potential to overcome these problems regarding nutrient balances in agricultural systems is life cycle assessment (LCA) (Haas et al., 2000). LCA assesses the integrated environmental impact of an agricultural activity, such as dairy production, throughout its entire life cycle. The aim of this article is to review prospects and constraints of LCA as a tool to assess environmental impact of conventional and organic animal production systems. This aim is illustrated using results from LCAs in the literature and from a pilot study concerning conventional and organic milk production.

2. Life cycle assessment

LCA is a method for integrated environmental impact assessment. Integrated, in this context, means that several environmental aspects (so-called environmental impact categories) are assessed simultaneously, varying from energy use to global warming, and that all processes involved in manufacturing of a product, from raw material extraction to possible waste treatments, can be incorporated into the analysis.

Initially developed to assess environmental impact of industrial processes, LCAs in agriculture have been carried out mainly for single crops, e.g., winter wheat, or for production processes, e.g., weed control or production of artificial fertiliser (Audsley et al., 1997; Ceuterick, 1996, 1998). Only recently, LCA was used to compare environmental impact of different agricultural production systems, such as conventional and organic milk production (Cederberg and Mattsson, 2000; Iepema and Pijnenburg, 2001; Haas et al., 2001). Before we can discuss LCA results of conventional and organic milk production, however, we will first describe the LCA framework.

2.1. Definition of goal and scope

Definition of goal and scope includes definition of the production system, the functional unit, the approach to co-product allocation and relevant environmental impact categories.

2.1.1. Production system

Ideally, an LCA assesses the environmental impact, clustered in so-called environmental impact categories, during all phases of the life cycle of a product. Applied to milk production, such an LCA encompasses all processes in the life cycle of milk, i.e., from production of dairy feed and artificial fertiliser up to milk storage and finally milk consumption. In order to compare the environmental impact of conventional and organic milk production, however, LCA case studies reviewed encompass processes relevant to produce milk only, and omit processes relevant to deliver and consume milk (products). The general flowchart of such a ‘cradle to farm-gate’ life cycle of milk production is given in Fig. 1. Agricultural LCAs often exclude production processes of medicines and insecticides, and of machines, buildings, and roads because of a lack of data (Cederberg and Mattsson, 2000; Iepema and Pijnenburg, 2001; Van Dijk, 2001).

2.1.2. Functional unit

The total environmental impact of milk production finally is referenced to the functional unit (FU). Definition of FU depends on the environmental impact category and the aim of the investigation. In most LCAs of agricultural products, FU has been defined as the mass of the product leaving the farm gate, e.g., kg of fat and protein corrected milk

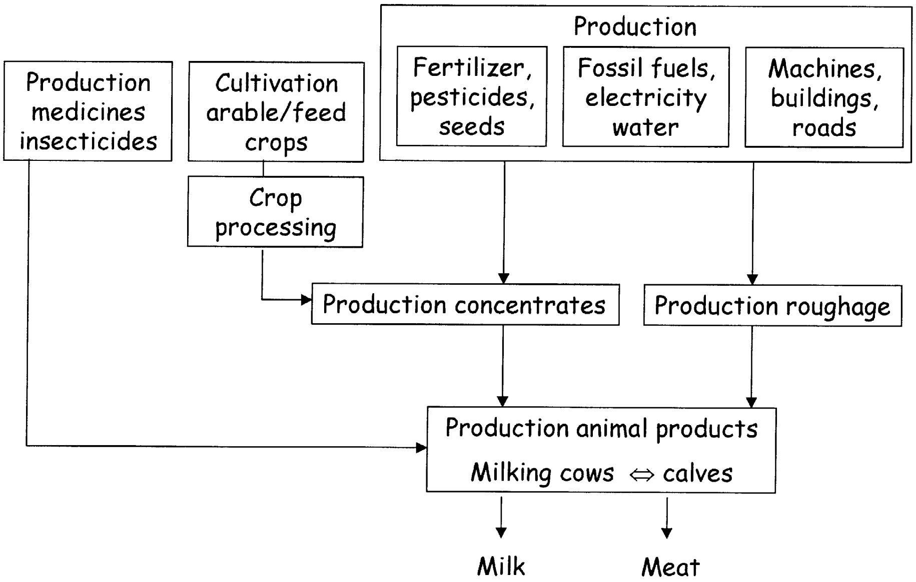

Fig. 1. A general flowchart of the 'cradle to farm-gate' life cycle of milk production.

(FPCM) (Cederberg and Mattsson, 2000; Iepema and Pijnenburg, 2001), or kg pig meat leaving the farm gate (Van Dijk, 2001; Cederberg and Dalerius, 2000, 2001). Few LCAs reference the environmental impact to total on-farm land use, for example, or even to the entire farm (Haas et al., 2001).

2.1.3. Approach to co-product allocation

Many crop or animal production systems produce more than one economic output, i.e., so-called co-products. The environmental impact during the production process of soy beans, for example, generally is allocated between its co-products oil and soy meal. Only the latter is used in concentrate feed for dairy cows. In agricultural LCAs, co-product allocation often is based on economic values of co-products (Cederberg and Mattsson, 2000; Iepema and Pijnenburg, 2001; Van Dijk, 2001; Cederberg and Dalerius, 2000, 2001). At present, system expansion is recommended to avoid co-product allocation (Weidema, 2001). System expansion, however, has not been applied yet in agricultural LCAs.

2.2. Environmental impact categories

An LCA of conventional versus organic milk production systems should include those environmental impact categories that are affected by these systems: acidification, eutrophication, global warming, toxicity, and use of resources. Ozone depletion is not considered, because current milk or meat production systems emit negligible amounts of substances affecting ozone depletion (Audsley et al., 1997; Van Dijk, 2001).

2.2.1. Acidification

Acidification is the emission of gasses (SO_2, NO_x, HCl, NH_3) into the air that combine with other molecules in the atmosphere and result in acidification of ecosystems (Audsley et al., 1997). For example, NH_3 neutralises atmospheric sulphuric or nitric acid and, when transformed into NH_4^+, is deposited on the soil. During soil nitrification of NH_4^+ into NO_3^-, H^+ is released. In a N-surplus situation, this release of H^+ eventually causes soil acidification. Acidification may result in a high aluminium concentration in ground water, which affects plant and root growth, increases risk of vegetation damage due to drought and diseases, and is toxic for animals and humans, depending on its concentration (Lekkerkerk et al., 1995).

2.2.2. Eutrophication

Eutrophication includes emission of substrates and gasses to the water and air that affect the growth pattern of ecosystems. N-eutrophication (for animal production, mainly NO_x, NH_x, NO_3^-), for example, has three main effects. First, the composition of vegetation changes towards N-loving species, which supersede rare plants typical of N-poor ecosystems. Second, the nutrient balance in the soil is disturbed, resulting in an increased risk of vegetation damage. Third, surplus N in the form of nitrate leaches to the ground water (Lekkerkerk et al., 1995). A high nitrate level in food or drinking water causes oxygen deficiency in blood, especially of small children (Davis, 1990).

P-eutrophication (mainly PO_4^-) results in excessive growth of algae and higher plants. When these overabundant plants die, their microbial degradation consumes most of the oxygen dissolved in the water, vastly reducing the water's capacity to support life (Sawyer, 1966).

2.2.3. Global warming

Solar energy drives the weather and climate on earth, and heats the earth's surface. In turn, the earth radiates energy back into space through ultraviolet radiation. Atmospheric greenhouse gasses (GHG) trap some of the outgoing energy and retain heat somewhat like the glass panels of a greenhouse. Without this natural greenhouse effect, however, the earth's temperature would be lower than it is now, and life as known today would not be possible (IPCC, 2001).

Human activities, such as fossil fuel burning and deforestation, are strengthening the earth's natural green house effect by increasing the level of GHG in the atmosphere (mainly CO_2, CH_4, and N_2O), also referred to as global warming. Rising global temperatures are expected, for example, to raise sea level, to alter forests, crop yields and water supplies, and to expand deserts. They might also affect human health, animals, and many types of ecosystems (IPCC, 2001).

2.2.4. Human and ecotoxicity

Human exposure to toxic substances, through air, water, soil or the food chain, can cause serious health problems. A toxicity assessment in agricultural LCAs focuses on the effect of exposure to pesticides and heavy metals on humans and ecosystems. Few exact figures, however, are available on the emission of heavy metals during the life cycle of animal products. Current LCAs of agricultural products have assessed toxicity only on emission of pesticides (Cederberg and Mattsson, 2000; Iepema and Pijnenburg, 2001; Van Dijk, 2001).

2.2.5. Use of resources

Previously, the possible lack of non-renewable resources (e.g., fossil fuels, water, land) was a hot topic for environmental debates. Nowadays, however, environmental damage resulting from the use of non-renewable resources, such as CO_2 emission from combustion of fossil fuels, is considered to be more important. Nevertheless, efficient use of resources, such as fossil fuels, water and agricultural land, remains an important environmental impact category in agricultural LCAs.

2.3. Environmental impact assessment

For each environmental impact category described in Section 2.2, we will review results of case studies that compare conventional and organic milk production systems. First, however, we list relevant characteristics of LCA case studies (Table 1), which is essential to interpret final results.

The Swedish case study compared LCA of a conventional and an organic experimental farm, with equivalent technology and processes (Cederberg and Mattsson, 2000). The Dutch case compared LCA of three experimental farms: a conventional farm, a conventional farm aimed at minimal environmental pollution (referred to here as environment-friendly farm), and an organic farm (Iepema and Pijnenburg, 2001). The German case compared LCA of 18 practical farms in three production systems: a conventional intensive, a conventional extensive, and an organic system (Haas et al., 2001).

Table 1 shows that life cycles of milk production were analysed from 'cradle to farm gate', i.e., from the moment raw material is extracted to the moment milk leaves the farm gate. Consequently, FU generally was defined as a mass value of the product leaving the farm gate. By relating environmental impact to mass value of the product, both production efficiency and environmental impact are considered. By relat-

Table 1
Characteristics of LCA case studies that compared conventional and organic milk production systems

Characteristic	LCA case studies		
	Swedish Cederberg and Mattsson (2000)	Dutch Iepema and Pijnenburg (2001)	German Haas et al. (2001)
System boundary	Cradle to farm-gate	Cradle to farm-gate	Cradle to farm-gate
FU	t ECM	kg FPCM	On farm grassland (ha) or t milk
Allocation			
General	Economic	Economic	Not described
Milk/meat	85/15 (biological)	86/14 (economic)	Not described
Studied farms	Experimental farms	Experimental farms	Individual, practical farms
Production systems	Conventional Organic	Conventional Environment-friendly Organic	Conventional, intensive Conventional, extensive Organic
Impact categories			
Acidification	Yes	Yes	Yes
Eutrophication	Yes	Yes	Yes
Global warming	Yes	Yes	Yes
Ecotoxicity	Yes	Yes	No
Energy use	Yes	Yes	Yes
Land use	Yes	Yes	No

t ECM is tonne energy corrected milk. The ECM correction factor considers the fat and protein content of milk. t FPCM is tonne milk corrected for its fat and protein content.

ing environmental impact to, on-farm land use, however, only environmental impact is considered. An FU related to mass value seems appropriate for an environmental impact category, such as global warming or resource depletion, because these categories operate on a global scale (Haas et al., 2000). In this review, therefore, we express global warming and resource depletion relative to a mass-related FU. For impact categories with a regional character, such as acidification and eutrophication, however, we express their environmental impact relative to a mass-related FU and an area-related FU.

2.3.1. Acidification potential

Different SO_2-equivalent factors were used to compute acidification potential (AP) of milk production systems: 1 for SO_2, 0.7 for NO_x (i.e., NO and NO_2), and 1.88 for NH_3 (Audsley et al., 1997; Reinhardt, 1997).

Table 2 shows that volatilisation of NH_3 contributes 78–97% to AP of milk production. NH_3 volatilises mainly from manure application on the field, from dairy barns, and during grazing. Volatilisation of NH_3 from the barn depends on four factors: cow's diet, barn design, indoor and outdoor climate, and farm management (De Boer et al., 2002). In the Dutch case, these factors were almost equivalent for the conventional and the organic production system (Iepema and Pijnenburg, 2001). The environment-friendly production system, however, was aimed at altering the cow's diet to reduce volatilisation of NH_3, and had a low-emission dairy barn (Green Label). This system, therefore, showed a lower AP than either the conventional or the organic system, independent of definition of FU (see Table 2).

In the Dutch case, definition of FU did not affect the conclusion with respect to AP, because production systems hardly differed in livestock density per ha of farmland (Iepema and Pijnenburg, 2001). In the German and Swedish cases, however, the organic and conventional system differed largely in livestock density per ha. As a result, organic production resulted in lower AP per ha of farmland, whereas AP per tonne of milk was almost equivalent or even higher than for conventional production. In the Swedish case, for example, AP per ha was 52 for organic production and 131 for conventional production, whereas AP per tonne of milk was 16 for the organic system and 18 for the conventional system.

Table 2
Acidification and eutrophication potential for several milk production systems

Case	Production system	Acidification potential (SO_2-equivalents/FU)					Eutrophication potential ($NO_3^{-\,a}$ or $PO_4^{-\,b}$-equivalents/FU)					
		FU		Contribution (%)			FU		Contribution (%)			
		t milk	ha	SO_2	NO_x	NH_3	t milk	ha	NO_x	NH_3	NO_3^-	PO_4^-
Swedish[a]	Conventional	18	131	3	7	90	58	433	4	53	41	2
	Organic	16	52	1.5	9.5	89	66	218	5	41	52	2
Dutch[a]	Conventional	10	116	12	10	78	69	820	3	21	15	61
	Environment-friendly	6	82	11	9	80	20	271	5	47	48	0
	Organic	10	115	9	12	79	34	396	7	44	24	25
German[b]	Conventional-intensive	19	136	1	4	95	7.5	54	–	–	–	–
	Conventional-extensive	17	119	1	4	95	4.5	31	–	–	–	–
	Organic	22	107	0.5	2.5	97	2.8	14	–	–	–	–

[a] Eutrophication potential expressed in NO_3^- equivalents per FU.
[b] Eutrophication potential expressed in PO_4^- equivalents per FU. The contribution of NO_x, NH_3, NO_3^-, PO_4^-, therefore, are not available.

2.3.2. Eutrophication potential

LCA case studies expressed eutrophication potential (EP) of milk production in either NO_3^- or PO_4^- equivalents (Table 2). Different NO_3^--equivalent factors were used: 1 for NO_3^-, 1.35 for NO_x, 3.64 for NH_3, and 10.45 for PO_4^- (Weidema et al., 1996). Different PO_4^- equivalent factors were used: 0.13 for NO_x, 0.42 for N-balance and 3.06 for P-balance (Heijungs et al., 1992).

Table 2 shows that NH_3, NO_3^- and PO_4^- contribute to the EP of milk production. Recall that volatilisation of NH_3 was not necessarily reduced by changing from conventional to organic milk production. Differences in EP between conventional and organic milk production, therefore, are due mainly to differences in leaching of NO_3^- and PO_4^-. Organic production, therefore, is expected to reduce EP, because of the absence of artificial fertiliser.

Table 2 indeed shows that organic milk production resulted in lower EP per tonne of milk and a lower EP per ha of farm land than conventional milk production, except for the Swedish case, in which EP per tonne of milk was higher for organic than for conventional production. There are two explanations for this exception. First, in the Dutch and German cases, all P not taken up by the plant was assumed to leach to the ground water or surface water. In the Swedish case, however, P-leaching per ha was fixed at only 0.35 kg/ha for conventional production and 0.25 kg/ha for organic production (Cederberg, 1998). The additional P-surplus was assumed to accumulate in the soil. The possibility for organic production to reduce leaching of P, therefore, was negligible. Second, the Swedish organic production system used peas as feed concentrates. For peas, however, nitrate leaching in relation to yield is relatively high (Cederberg, 1998).

2.3.3. Global warming potential and energy use

Different CO_2-equivalent factors were used to compute global warming potential (GWP) of milk production: 1 for CO_2, 21 for $CH_{4,}$ and 310 for N_2O (Audsley et al., 1997, assuming a 100-years time horizon).

Table 3 shows that the GWP of milk production is for 48–65% due to emission of CH_4. CH_4 is a by-product from anaerobic bacterial fermentation of carbohydrates (mainly cellulose) present in feed and excreta. In animals, CH_4 production depends on animal size and type, and on feed intake and digestibility (Wilkerson et al., 1994). Emission of CH_4, therefore, decreases as production level or feed digestibility increases (Corré and Oenema, 1998). In Europe, however, possible reduction of CH_4 emission is limited because of the already high levels of milk production and feed digestibility (Corré and Oenema, 1998). Changing from conventional to organic milk production, however, will increase CH_4 production because of the, on-average, lower milk production level per cow and increased use of

Table 3
Global warming potential (GWP) and energy use for several milk production systems

Case	Production system	Global warming potential (CO_2-equivalents/FU)				Energy (GJ/FU)
		GWP	Contribution (%)			
			CO_2	CH_4	N_2O	
Swedish	Conventional	990	18	52	30	2.8
	Organic	942	16	64	20	2.4
Dutch	Conventional	888	36	48	16	3.7
	Environmental-friendly	689	32	53	15	2.4
	Organic	922	38	53	9	3.9
German	Conventional, intensive	1300	14	54	32	2.7
	Conventional, extensified	1000	10	65	25	1.3
	Organic	1300	7	65	28	1.2

roughage. Organic milk production, therefore, can achieve a lower GWP only by reducing emission of CO_2 and N_2O.

Emission of CO_2 in milk production results mainly from combustion of fossil fuels at the farm (±22%), and during production and transport of concentrates (30%) and artificial fertiliser (21%) (Hageman and Mandersloot, 1995). Although EU regulations on organic production do not address the use of non-renewable energy resources (Anonymous, 1999b), organic production is expected to use less fossil fuel per tonne of milk than conventional production, because of the absence of artificial fertiliser and the relatively low use of concentrates in the cow's diet. Table 3 shows that fossil fuel use per tonne of milk generally is lower in the organic than in the corresponding conventional system, except for the Dutch case. In the Dutch case, the organic system used a commercial organic concentrate with a high content of dried grass (22%). Grass drying is an energy consuming process, which explains the high GWP and use of energy per tonne of milk for the organic system.

Emission of N_2O results from denitrification in soil and in slurry. The process (conditions) of N_2O production is understood poorly, and, consequently, few data on N_2O emission are available. In LCAs, therefore, normative values are used that may not reflect practical N_2O emission levels. From Table 3, we can compute that N_2O emission from organic milk production is lower than for conventional production in all cases. This reduction of N_2O is achieved by matching fertiliser application rates to crop requirements.

Unlike reduced emissions of CO_2 and N_2O, GWP of organic milk production is similar to GWP of conventional production (see Table 3). The reduction in GWP due to reduced emission of CO_2 and N_2O in organic production is nullified by its inherent increase of methane emission.

2.3.4. Pesticides and land use

Only the Dutch and Swedish cases quantified use of pesticides and land. Use of pesticides was lower for organic than for conventional production, whereas land use was higher. Pesticide use was computed differently in each case, and therefore, not comparable between cases. In Sweden, production of a tonne of milk required 1925 m^2 for conventional and 3464 m^2 for organic production (Cederberg, 1998; Cederberg and Mattsson, 2000), whereas in The Netherlands a tonne of milk required 970 m^2 for conventional, 820 m^2 for environment-friendly, and 1180 m^2 for organic production (Iepema and Pijnenburg, 2001). Organic production increased land use per FU, due to decreased crop yields per ha. The difference in land use between conventional and organic production was larger in Sweden than in The Netherlands, which is due to a larger difference in composition of concentrate feed between organic and conventional production in Sweden. In Sweden, conventional concentrates contain large amounts of co-products from the oil or sugar industry, whereas organic concentrates contain a large amount of a main product, i.e., peas (Cederberg and Mattsson, 2000). Compared to a main product such as peas, a co-product from the oil or sugar industry has a relatively low allocation value (both economic and mass allocation), and therefore, a low impact on, e.g., land use.

3. Discussion

At present we cannot directly compare results of different LCA studies (Tables 2 and 3). The absolute GWP, for example, differed largely among studies because of differences in allocation or normative values used with respect to CH_4 and N_2O emission. Similarly, absolute levels of EP were not comparable because of differences in equivalence factors used. A direct comparison of results of different LCA studies, therefore, requires further international standardisation of the LCA method (Van Koppen and Meeusen, 2001).

At this moment, conventional and organic production systems can be compared only within a case study. Studies reviewed here confirmed that AP of milk production is due mainly to NH_3 emission (i.e., 78–97%), which is not reduced necessarily by organic production. As expressed per ha of farm land, differences in AP between conventional and organic production were due to differences in livestock density.

EP per tonne of milk and per ha, however, is lower for organic milk production than for conventional. Organic milk production potentially reduces leaching of NO_3^- and PO_4^- due to lower fertiliser application rates.

Organic milk production can reduce GWP only by reducing emission of CO_2 and N_2O. Emission of CH_4 explains 48–65% of GWP in milk production, and the percentage increases by changing from conventional to organic production. Few exact figures, however, are available especially on the amount of N_2O and CH_4 emitted from dairy cattle production (Monteny et al., 2001). Current LCAs use normative values that might not reflect variation in emissions observed in practice.

Conclusions regarding potential environmental impact of conventional and organic milk production are based largely on comparison of experimental farms, which do not necessarily represent corresponding production systems. To show differences in potential environmental impact among various production systems, however, LCAs should be performed at a large number of practical farms for each production system of interest (Haas et al., 2001). Application of LCA on practical farms, however, requires in-depth research to understand underlying processes, and to predict, or measure, variation in emissions (e.g., NH_3, CH_4 and N_2O) (De Boer et al., 2002; Monteny et al., 2001). In addition, current agricultural LCAs assess only the potential environmental impact of the production of an agricultural product. The environmental impact realised locally can be highly variable, depending on, local climate and soil type, for example (Wegener Sleeswijk et al., 1996).

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