The Potential Use of Organically Grown Dye Plants in the Organic Textile Industry: Experiences and Results on Cultivation and Yields of Dyer's Chamomile (*Anthemis tinctoria* L.), Dyer's Knotweed (*Polygonum tinctorium* Ait.), and Weld (*Reseda luteola* L.)

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ABSTRACT. The organic cultivation of dye plants for the certified natural textiles industry is an emerging and promising sector of organic farming. In 1999 a field trial was done with different provenances of

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Dyer's Chamomile (*Anthemis tinctoria* L.), Dyer's Knotweed (*Polygonum tinctorium* Ait.), and Weld (*Reseda luteola* L.) on two organic farms in Lower Austria. Yields, dyestuff content, and quality parameters were analyzed. Dry matter yields of Weld ranged between 0.7 and 2.7 t ha^{-1}, of Dyer's Chamomile (flower heads) between 1.1 and 1.8 t ha^{-1}. Significant differences were found between seed Weld provenances as well as between those of Dyer's Chamomile. The total leaf dry matter of Dyer's Knotweed (2 cuts) ranged at both sites on average 3.1 t ha^{-1}. Seed provenances did not show differences. The total flavonoid content of Weld ranged between 1.53 and 4.00%, of Dyer's Chamomile between 0.84 and 1.5%. The content of indican in Dyer's Knotweed ranged between 0.50 and 1.45% of leaf dry matter, the calculated theoretical content of indigo ranged between 0.22 and 0.64% of leaf dry matter. The general use fastness properties differ according to species and provenance. Both high and low values were achieved. The data on the cultivation of dye plants in organic farming show promising results. Research should address improvement in yields and quality, development of dyestuff extracts, and optimization of dyeing methods. Research on dye plants needs a systemic look at the whole chain including producers, processors, trade, and consumers.

KEYWORDS. Dye plants, organic farming, natural textiles, natural colors, renewable resources

INTRODUCTION

Until the 19th century, natural colors obtained from plants and animals,[1] as well as mineral pigments, were used for coloring. From the Middle Ages on, the cultivation of dye plants and the further processing and dyeing became an important economic factor in Europe, e.g., Woad (*Isatis tinctoria* L.) in Thüringen, Germany, and Madder (*Rubia tinctorum* L.) in The Netherlands and southern areas of France (Meyer, 1997). With the invention of chemical synthetic dyes (aniline in 1856, synthetic alizarin in 1869, and synthetic indigo in 1878; Hofmann, 1989), natural dyes lost their economic significance.

At present, dyeing with dye plants is done by artisans, craftsmen, and green-minded companies at three different technological levels (Hartl, 1997):

a. At the handicraft level, one or two people use simple equipment, such as pots, gas cookers, and adapted washing-machines. They mainly dye wool (fleece and yarns) and silk, because these materials can be more easily dyed than cellulose fibers such as cotton, linen, or hemp. Products offered are: dyed knitting wool and wool fleece, scarves, pullovers, socks, etc.
b. At the small enterprises level machines are used, which are also common in conventional dyehouses (e.g., 1800 l-kettles, small kettles for producing the dyeing liquor by boiling out dye stuff, facilities to lift the yarns from the kettle, a centrifugal drier, and a heat pump). At these facilities 50 kg of yarn can be dyed per unit, for larger amounts conventional dyehouses are rented.
c. For dyeing at the industrial level, dyeing systems have been developed which consist of dyestuff, pre- and post-treatments, and textile auxiliaries. These systems are applicable to various materials (e.g., wool, silk, cotton, linen, hemp, leather, accessories made of horn, nutshells, mother-of-pearl) and various dyeing machines.

Dried dye plants are used at all levels. Boiling out the plants in water, the dyestuff is extracted by the dyers themselves. Dyeing with ready made dyestuff extracts on the industrial scale is still at the research and development level.

Since the 90s, research institutions in Germany, Italy, England, France, the Netherlands, and Austria have been dealing with research for the re-introduction of natural dyes. The reasons for this new scientific interest are based on a growing awareness to find sustainable and non-toxic alternatives to synthetic dyes, a growing market of natural textiles, and the search for additional, economically viable alternative crops for farmers.

The aim of our research project is to provide information regarding research, the cultivation and processing of organic fiber and dye plants for use with natural textiles, as well as the trade and distribution of these products. In this paper, we summarize published data on dye plants and we present the results of our field trial with three species of dye plants. The aim is to give the first quantification of yield, dyestuff content, and dyeing quality of three seed provenances per species, cultivated under the conditions prescribed by organic farming. Dyestuff content and dyeing quality are also compared with samples of those species commercially available and/or used by dyers.

RELEVANT LITERATURE

Selection of Plant Species Suitable for Modern Cultivation and Dyeing

About 1,100 plant species can be used for dyeing (Hofmann, 1989). Therefore it is an important aim in research to screen and select species which fit for modern sustainable cultivation techniques as well as for dyeing on a large scale.

At the *Thüringer Landesanstalt für Landwirtschaft* (Germany), 108 dye plant species are assessed on the basis of their suitability for modern cultivation systems, on yields, and on dyeing quality. Of these species, 19 species were considered as useful for cultivation and dyestuff production. Madder (*Rubia tinctorum*), Weld (*Reseda luteola*), Canadian Golden Rod (*Solidago canadensis*), Dyer's Chamomile (*Anthemis tinctoria*), and Dyer's Knotweed (*Polygonum tinctorium*) are considered to play a decisive role in future dye plant cultivation and processing (Biertümpfel et al., 2000). Nevertheless, other species may also become important for dyeing, as the recent example of Rhubarb (*Rheum rhabarbarum*) shows: it is perfectly suitable for the dyeing and tanning of leather and is already used in practice by one company (Schellenberg et al., 1999).

Cultivation, Harvesting and First Processing

Depending on the species, dye plants have not been bred or at least, up to now, only to a small extent. They are therefore, extremely variable in their morphological and phytochemical characteristics. Registered varieties do not exist yet. There are only different provenances of seed available. Therefore, the aim of a current research project conducted by the *Thüringer Landesanstalt* is to improve provenances concerning yield, dyestuff content, and agrotechnological suitability (Biertümpfel & Vetter, 1999).

Sowing

All dye plants except Madder have extremely fine seeds and therefore high requirements on soil preparation. The drilling of dye plants has shown to be cheaper than planting (Vetter, 1994). It is possible to use drilling for all dye plant species which were tested by the *Thüringer Landesanstalt für Landwirtschaft*, except Canadian Golden Rod. The seeds of C. Golden Rod have a 1000-kernel-mass of 0.03-0.06 g and are too small for drilling. The higher costs for planting, however, are compensated by the fact that this species has a useful life of several years (Wurl, 1997).

Weed Control

Weed control in dye plants is necessary especially in the early growth stages. For conventional cultivation methods no herbicides are legally registered in Europe and therefore the risk of damages due to the use remains with the farmers. The *Thüringer Landesanstalt* as well as the *Landesanstalt für Landwirtschaft des Landes Brandenburg* are conducting research on the use of herbicides in dye plants (Wurl, 1997; Vetter et al., 1999; Adam et al., 1997; Adam & Dittmann, 1999). Weld and Dyer's Knotweed have reacted sensitively to the tested herbicides (Vetter et al., 1999; Adam & Dittmann, 1999). The published cultivation instructions (TLL, 1999) also explain techniques of mechanical weed control. These techniques are the classical procedures of proper mechanical weed management used by organic farmers.

Fertilization

Dyer's Knotweed has a high demand for nitrogen. With regard to phosphorus and potassium, it is not so demanding. The other species, Weld and Dyer's Chamomile, have a low demand for nitrogen. Excessive nitrogen fertilization leads to negative effects on yield: the dyestuff content of Weld is reduced by high levels of nitrogen fertilization and Dyer's Chamomile should not be fertilized with nitrogen at all, because this would reduce the development of flower heads (Table 1) (TLL, 1999).

Supply of nutrients under conditions of organic farming for the cultivation of spices and herbs by organic manure, proper crop rotation, and preceding crops (incl. catch crops) is done successfully at many farms (Hartl & Vogl, 2000a) and should be possible for dye plants, too.

Harvest

The same harvesting equipment that is used in herb and spices cultivation can be used for dye plants, too (Vetter, 1997). High harvesting costs are caused by the harvest of flowers, followed by roots and leaves or whole plants (Vetter, 1994). Dye plants of which the whole plant or

TABLE 1. Recommended fertilization for selected dye plant species.

Species	Recommended fertilization (cultivation instructions, TLL 1999)		
	N (kg ha^{-1})*	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
Weld, *Reseda luteola*	0-60	50	250
Dyer's Chamomile, *Anthemis tinctoria*	no N-fertilization	30	70
Dyer's Knotweed, *Polygonum tinctorium*	150-200	no data available	
Canadian Golden Rod, *Solidago canadensis*	60-100	no data available	no data available
Madder, *Rubia tinctorum*	120-160	100	240

* taking $nitrate_{min}$ in the soil into consideration

the leaves are used for obtaining dyestuff (like Weld and Dyer's Knotweed) can be harvested with the harvesters that are also used to harvest fodder. Nevertheless, it is important that the storage box at the harvester is not too large and that it is emptied regularly. The increase of temperature in densely stocked piles reduces quality by the decomposition of phytochemicals (Dachler & Pelzmann, 1989). As proved in a field trial under practical management conditions (Biertümpfel, 1997), adapted chamomile picking machines can be used for harvesting the flower heads of Dyer's Chamomile. Data of yields per ha of dye plants are available only from field trials conducted on conventional farms (Table 2).

Except Dyer's Knotweed, whose dyestuff indigo is gained from fresh plants, all other dye plants require a quick and careful drying right after harvesting to preserve phytochemicals until extraction. The same drying technology that is used in herb and spice production can also be used for drying dye plants (Dachler & Pelzmann, 1989). The drying method (temperature, time spent in the dryer) and the degree to which the harvested material is crushed have an influence on the content of phytochemicals in the dyeing substance and on the efficiency of the dyestuff extraction (Adam & Dittmann, 1999).

Dyestuff Content and Factors Influencing Quality

Like essential oils or tanning agents, plant dyes are secondary plant metabolites (Nultsch, 1986). Dyestuff (Table 3) is contained in the whole plant or only in certain parts like flowers, leaves, roots, bark, or wood (Hofmann, 1989). Plant species always contain several components of dyestuff (cf. Schweppe, 1992; Roth et al., 1992) and for many plant species not all components have been identified yet (e.g., for Dyer's

TABLE 2. Yields of Weld, Dyer's Chamomile and Dyer's Knotweed (conventional farming).

Species	Yield (t ha^{-1})		Literature cited
Weld, *Reseda luteola*	3.5-7	dry matter yield of whole plants	Wurl 1997
	5		TLL (1999)
	4-4.5		Adam & Dittmann (1998)
Dyer's Chamomile, *Anthemis tinctoria*	2-2.5	dry matter yield of flower heads	TLL (1997), Vetter et al. (1999)
Dyer's Knotweed, *Polygonum tinctorium*	20-30	fresh weight of whole plants	TLL (1999)

TABLE 3. Dyestuff content of Weld, Dyer's Chamomile and Dyer's Knotweed (literature overview).

Species (plant organ containing dyestuff)	Dyestuff content (% dry matter)	Literature cited
Weld	2-4% (luteolin, luteolin-3,7-diglucoside, luteolin-7-glucoside and apigenin)	TLL (1997)
(whole plant, especially	1-1.86% (type of dyestuff unknown)	Biertümpfel & Vetter (1999)
the blossoming sprouts)	1-2.9%, on average 1.9 % (content of flavonoids)	Kaiser (1993)
	2.5% total dyestuff content*	Adam & Dittmann (1999)
Dyer's Chamomile	4-5% dry matter of flower heads (type of dyestuff unknown)	Vetter et al. (1999)
(flower head)	min. 2.54% and max. 6.82% (type of dyestuff unknown)	Biertümpfel & Vetter (1999)
Dyer's Knotweed	4-5% of leaves (dyestuff precursors)	TLL (1999)
(fresh leaves)	2.55-4.49% indigo content in leaf dry matter	Vetter et al. (1999)
	min. 2.06% and max. 6.37% indigo content in dry matter	Biertümpfel & Vetter (1999)
	1-5 g indigo/kg leaf fresh weight	Hill (1993)
	3.2% indigo content in the leaves of the first cutting, 1.6-1.9% in the leaves of the second cutting**	Yonekawa (1993)

* Calculated as the sum of luteolins (luteolin-3,7-glucoside; luteolin-7-glucoside; luteolin-8-0-glucoside orientin; luteolin) and other flavonoids (apigenin, kaempferol), Adam & Dittmann (1999)
** Yonekawa (1993) does not provide information if %-data refer to fresh weight or dry matter

Chamomile, *Anthemis tinctoria* L., the main component has not yet been identified).

The dyestuff can be extracted from the dried plant material by using dissolvent (e.g., water, alcohol). The extraction method of indigo, however, is different and more complicated. Indigo is a vat dye. Plants always contain precursors of indigo: Dyer's Knotweed contains indican and perhaps also indirubin (Schweppe, 1992). The precursors are transformed via (enzymatic) hydrolysis into indoxyl, which is transformed oxidatively into indigo.

Vat dyes are organic pigments which are insoluble in water. During the dyeing process, they can only be fixed on the fiber after being transformed into a soluble substance (leuco base) via reduction. The fibers are put into this soluble substance. After oxidation in the air, the indigo pigment is formed again and now set in the fiber (Hofmann, 1989).

The dyestuffs of Weld and Dyer's Chamomile (flavonoids) are mordant dyes. They need a mordant to be fixed on the fiber, in most cases metal salts are used (Hofmann, 1989).

The aim of dye plant cultivation should not only be a high hectare yield but also a product of high quality (which means high content of valuable phytochemicals), with few foreign elements and free of toxic residues (Wurl, 1997; Vetter, 1997). The following factors have an influence on quality (summarized according to Wurl, 1997; Adam & Dittmann, 1999; Vetter, 1997; Biertümpfel, 1997):

- Careful selection of the suitable site for cultivation, taking into account parameters of soil and climate;
- Use of appropriate provenances (seed purity, germinating power, homogeneity, high yield, high dyestuff content, good suitability for dyeing, good technological suitability);
- Proper management to ensure fast soil cover (higher planting/seeding density, time of drilling or planting, efficient weed control, crop rotation, irrigation);
- Selection of the optimal harvesting time, height of cutting, daily progression;
- Gentle post-harvest treatment which guarantees a good quality (influence of temperature and drying time on dyestuff content, influence of the degree of reduction on dye yields during extraction);
- Cultivation of units large enough to achieve constant quality.

The dyestuff content is an essential criterion for quality. The metabolism of the different phytochemicals during the dyeing process is not yet clear, i.e., which phytochemicals hinder and which promote the dyeing process. The lack of standardized analytical methods has prevented comparisons from being made among site influences, seed provenance, and cultivation methods tested by various authors.

MATERIALS AND METHODS

Scientific Field Trial

The field trial was conducted with Dyer's Chamomile (*Anthemis tinctoria* L.), Dyer's Knotweed (*Polygonum tinctorium* Ait.) and Weld (*Reseda luteola* L.) on two organic farms in Lower Austria (Glinzendorf and Dörfles; Table 4) for the duration of one year. The preceding crop at Glinzendorf was winter barley. After being harvested, oil radish mixed with tansy phacelia was sown as the catch crop in Glinzendorf. In Dörfles the preceding crop was summer barley. Peas were sown as the catch crop there.

Both sites are situated in the drier part of Lower Austria. The annual mean temperature is 9.8°C (Groβenzersdorf near Glinzendorf) and 9.9°C (Gänserndorf near Dörfles). Both sites showed an almost identical temperature pattern in 1999. The precipitation rates in the main growing period from April to September were also almost identical (except for April and June with higher precipitation in Dörfles). The average sum of annual precipitation is 550 mm (Groβenzersdorf near Glinzendorf) and 520 mm (Gänserndorf near Dörfles) (ZAMG, 1999).

These species were chosen for the field trial due to their suitability with respect to the following points (such features being beneficial to the future cultivation of dye plants in organic farming):

- cultivation instructions for conventional farming methods have already been published (TLL, 1999; Adam & Dittmann, 1998). Adoption of the recommended techniques to the necessities of organic farming are possible;
- harvest is possible after one vegetation period and results are therefore soon available;
- demand for nitrogen in Weld and Dyer's Chamomile is low (TLL, 1999) and therefore fit the requirements of organic farming;
- reports show few problems with weeds except in the early growth of all three species (TLL, 1999);
- species cover the basic colors yellow (Weld and Dyer's Chamomile) and blue (Dyer's Knotweed);
- good general use fastness properties were reported (Biertümpfel, 1997).

The tested seed provenances came from German seed companies and from German, Austrian and Japanese research institutions.

TABLE 4. Soil conditions at Dörfles and Glinzendorf.

DÖRFLES										
		Reseda luteola			Anthemis tinctoria			Polygonum tinctorium		
Sampling depth	(cm)	**0-25**	**25-50**	**50-75**	**0-25**	**25-50**	**50-75**	**0-25**	**25-50**	**50-75**
N_{min}	(kg/ha)	80	58	13	79	68	12	79	64	16
Total nitrogen	(%)	0.20	0.15	0.04	0.20	0.11	0.03	0.20	0.14	0.06
Humus from TOC	(%)	6.4	7.0	0.8	4.1	3.8	0.4	4.2	3.0	1.8
pH in $CaCl_2$	(pH)	7.6	7.8	7.9	7.6	7.7	7.9	7.6	7.7	7.8
Lime-test		5	5	5	5	5	5	5	5	5
Carbonate ($CaCO_3$)	(%)	12.2	20.0	31.8	12.9	16.1	38.3	12.9	18.2	25.4
P_2O_5 in CAL/DL	(mg/100 g)	21	6	< 3	20	5	< 3	22	7	< 3
K_2O in CAL	(mg/100 g)	32	10	< 3	32	10	< 3	34	12	< 3
GLINZENDORF										
		Reseda luteola			Anthemis tinctoria			Polygonum tinctorium		
Sampling depth	(cm)	**0-25**	**25-50**	**50-75**	**0-25**	**25-50**	**50-75**	**0-25**	**25-50**	**50-75**
N_{min}	(kg/ha)	57	26	13	65	20	7	46	19	6
Total nitrogen	(%)	0.15	0.15	0.13	0.20	0.22	0.21	0.15	0.11	0.08
Humus from TOC	(%)	3.0	2.9	1.7	2.9	2.9	1.7	2.9	1.8	0.1
pH in $CaCl_2$	(pH)	7.6	7.7	7.6	7.6	7.7	7.7	7.6	7.7	7.7
Lime-test		5	5	5	5	5	5	5	5	5
Carbonate ($CaCO_3$)	(%)	9.7	12.9	22.2	11.3	12.5	20.2	11.7	19.0	24.6
P_2O_5 in CAL/DL	(mg/100 g)	34	8	< 3	25	7	< 3	23	5	< 3
K_2O in CAL	(mg/100 g)	28	8	< 3	24	6	< 3	19	4	< 3

* The soil analysis was conducted by the *Bundesamt & Forschungszentrum für Landwirtschaft, Vienna*
Sampling: 07.05.1999. TOC = total organic carbon

The experimental design (Table 5) has been a systematic long plot design with four pseudo replications as described by Munzert (1992). The design had been chosen due to the technical characteristics of the planting/seeding equipment, which did not allow proper work of the equipment in a classical randomized block design.

The planting of seedlings was chosen instead of the recommended drilling (TLL, 1997 and 1999; Adam & Dittmann, 1998) to ensure establishment of the experiment. Following organic cultivation in the greenhouse for four to five weeks, the young plants were planted with planting machines. Both field trials were irrigated after the planting.

Weeds emerged, especially in Dyer's Knotweed. Dyer's Chamo-

TABLE 5. Research design.

		Weld	Dyer's Chamomile	Dyer's Knotweed
Factors		3 seed provenances	3 seed provenances	3 seed provenances
Sites		2	2	2
Number of replications per provenance		4	4	4
Plot size****		6 m^2	9 m^2	24 m^2
Tested variables	**yield**	fresh weight,** dry matter	fresh weight,** dry matter	fresh weight,** dry matter
	dyestuff content and dyestuff composition	Content of luteolin, apigenin and total flavonoid content (HPLC)	Extraction and analyzing of total flavonoid content (HPLC)	Extraction and analyzing of indigo precursors (HPLC)
	dyeing	Test of general use fastness properties and reflectance measurement	Test of general use fastness properties and reflectance measurement	Test of general use fastness properties and reflectance measurement
Additional data recorded (not presented here!)		height, pests and diseases, weeds	height, pests and diseases, weeds	height, pests and diseases, weeds
Number of samples (field trial)		**For analysis of content and experimental dyeing:** 2 samples (one mixed sample of replication no. 1 + 2 and one mixed sample of replication no. 3 + 4) per provenance and site in total 12 samples	**For analysis of contents and experimental dyeing:** 2 samples (one mixed sample of replication no. 1 + 2 and one mixed sample of replication no. 3 + 4) per provenance and site in total 12 samples	**For analysis of contents:** 4 samples and 2 cutting dates, per provenance and site, in total 48 samples **For experimental dyeing:** 1 sample per provenance and replication, one site in total 12 samples
Number of samples commercially available, that have been used as references		3	3	3
Total number of samples***		15	15	48 (for analysis of contents) and 15 (for dyeing)

* The first and the second cutting were both used separately for analysis of phytochemicals and measurement of yield
** Biomass as harvested
*** Each sample was analyzed twice for dyestuff content and dyestuff composition
**** The size of the plots was calculated according to the amount needed for dyestuff analysis and dyeing analysis

mile, however, established such a dense crop that as soon as crop covering had been reached, weed control was not necessary. Weld was seriously infested with fungal disease (*Cercospora resedae*). Some of the singular Dyer's Knotweed plants were infested with an unidentifiable viral disease. Dyer's Chamomile was not infested with any pests or diseases at all.

Harvesting dates were chosen according to the recommendations given in cultivation instructions (TLL, 1997 and 1999; Adam & Dittmann, 1998).

Weld and the flower heads of Dyer's Chamomile were dried after harvesting. Dyer's Knotweed was cut twice at each site. The content of indican, which is the precursor of indigo, can only be analyzed from fresh plant material (leaves). The precursors are very unstable. Indican can easily be changed into indigo by pressure or injury of the plant. Indigo, which is formed already in the plant, however, is lost to the chemical analysis. Samples of leaves, therefore, were picked by hand, then cooled and prepared in the laboratory immediately after picking. As opposed to Weld or Dyer's Chamomile, the indigo of Dyer's Knotweed has to be extracted immediately after cutting, without drying. The method used for extraction was based on Wurl et al. (1999). For a detailed description of the adapted method see Hartl and Vogl (2000c). It was originally planned to extract the plant material from the first cutting at both sites. The extraction of the material from Glinzendorf, however, failed because of difficulties in filtering off the indigo. The exact data on cultivation methods, harvesting, first processing, and sampling methods used are given in Table 6.

Analysis of Dyestuff Content and Dyeing Quality

The dyestuff content and dyeing quality of the field trial samples were compared with commercially available samples of Weld and Dyer's Chamomile (three samples each). Because indigo obtained from Dyer's knotweed is not available on the market, three samples of indigo taken from the tropical indigo plant (*Indigofera* sp.) were used in analyzing and comparing dyestuff quality.

The dyestuff content was analyzed with the HPLC method (Table 7). Each sample was analyzed twice.

For analysis of dyeing quality parameters, a comparative dyeing (mordant dyeing with Weld and Dyer's Chamomile and vat dyeing with the indigo of Dyer's Knotweed) was conducted under standardized conditions. The processes were not optimized as far as dye absorption is concerned. The samples from the field trial were compared with the commercially available samples. The dyeing quality was analyzed by a calorimetric valuation, and testing of the general use fastness properties (light fastness, rub fastness, fastness to perspiration, wash fastness). For a detailed description of dyestuff content analytical methods and the analysis of dyeing quality, see Hartl and Vogl (2000c).

Statistic Analysis

The data collected in the field trial and the data of the indican analysis of Dyer's Knotweed were statistically tested (the one way analysis of variance and Tukey-Test was done with the statistic program SPSS 7.5;

TABLE 6. Cultivation, harvesting, and first processing methods and dates.

	Weld		Dyer's Chamomile		Dyer's Knotweed	
	Glinzendorf	**Dörfles**	**Glinzendorf**	**Dörfles**	**Glinzendorf**	**Dörfles**
Planting date	18 May	19 May	18 May	19 May	18 May	19 May
Row distance	45 cm	45 cm	45 cm	45 cm	45 cm	45 cm
Planting distance in the row	~ 30 cm	~ 30 cm	~ 30 cm	~ 30 cm	~ 20 cm	~ 20 cm
No. of rows per plot	6	3	6	3	6	3
No. of plants per m^2*	6	5	6	5	10***	9***
Irrigation	Several times, exact data not available	19 + 26 of May, 12.5 mm each	Several times, exact data not available	19+ 26 of May, 12.5 mm each	Several times, exact data not available	19 + 26 of May, 12.5 mm each
Mechanical weed control	31 May, 17 June, 14 July	30 May, 18 June, 15 July	31 May, 17 June, 14 July	30 May, 18 June, 15 July	31 May, 17 June, 14 July	30 May, 18 June, 15 July
Harvesting date	20 July	20 July	04 August, 31 August	18 August, 13 Sept.	28 July, 17 Sept.	10 Aug., 07 Oct.
Harvesting method	Cutting of whole plants (1×)	Cutting of whole plants (1×)	Picking of flower heads with combs (2×)	Picking of flower heads with combs (2×)	Cutting of whole plants (2×)	Cutting of whole plants (2×)
Further treatment of harvested material	Drying (40°C) and cutting	Drying (40°C) and cutting	Drying (40°C, 60°C**)	Drying (60°C)	drying (60°C) for determination of dry matter yield	(a) drying (40 and 60°C) for determination of dry matter yield (b) for indigo extraction: harvested, not dried biomass of 1st cutting
Sampling for analysis of dyestuff	1 mixed sample of replication no. 1 + 2 and 1 mixed sample of replication no. 3 + 4 (each à 500 g per seed provenance) in total: 6 samples	Same as site Glinzendorf	Same as for Weld, site Glinzendorf	Same as for Weld, site Glinzendorf	1 sample of fresh leaves per replication, seed provenance and cutting in total: 24 samples	1 sample of fresh leaves per replication, seed provenance and cutting in total: 24 samples
Sampling for analysis of dyeing quality	1 mixed sample of replication no. 1 + 2 and 1 mixed sample of replication no. 3 + 4 (each à 50 g per seed provenance) in total: 6 samples	Same as site Glinzendorf	Same as for Weld, site Glinzendorf	Same as for Weld, site Glinzendorf	No samples, extraction had to be stopped	1 sample of extracted indigo per seed provenance and replication (first cutting) in total: 12 samples

* Because of different driving speed the number of plants per m^2 also differed (17.06, shown is the average of all origins and repetitions)
** Second harvest dried at 60°C
*** Calculated on the basis of number of plants on a length of 2 m (average of 3 measurements per plot)

TABLE 7. Analysis of dyestuff content.

	Weld	Dyer's Chamomile	Dyer's Knotweed
Dyestuff group	Flavonoids (main dyestuff component: different glycosides of luteolin)	Flavonoids (main dyestuff component still not identified)	Indigo
Dyestuff analyzed as	Luteolin and glycosides (luteolin-3,7-diglucoside, luteolin-7-glucoside); apigenin; other flavonoids (kaempferol, quercetin u.a.) calculated as quercetin and analyzed as aglycons.	Total flavonid analysis. Calculated as quercetin. Analyzed as aglycons.	The content of indican glycosides (indigo precursors) was analyzed and converted into the content of indigo.

the influence of the seed provenances was considered as significant at $p \leq 0.05$). In figures, different letters (a, b, c) indicate significant differences. The results of the dyestuff content analysis of Weld and Dyer's Chamomile were not statistically tested because of the small number of samples (the first and the second replication were mixed to make sample one, the same was done with the third and the fourth replication for sample two).

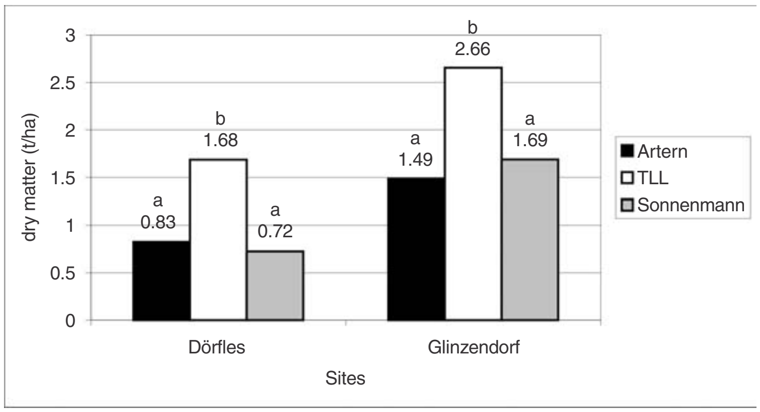
RESULTS AND DISCUSSION

Dry Matter Yield

The dry matter yields of Weld ranged between 0.7 and 2.7 t ha^{-1} (Figure 1). At both sites the dry matter yield of the seed provenance 'TLL' was significantly higher than the dry matter yield of the provenances 'Artern' and 'Sonnemann' (the difference is about 1 t ha^{-1}). In Glinzendorf, the yields of all three tested provenances were higher than in Dörfles. It can be presumed that in addition to the differences of site, the stronger infestation with *Cercospora resedae* in Dörfles (the phytopathological assessment according to Wagner and Prediger (1990) showed on average a one degree stronger infestation) and the unintentionally lower planting density (Table 6) in Dörfles also had a negative influence on the dry matter yield.

With a maximum dry matter yield of 2.7 t ha^{-1}, the yields are well below the yields of 4-5 t ha^{-1} achieved by conventional farming in Thüringen and Brandenburg (Germany) (Adam & Dittmann, 1998; TLL, 1999). One possible reason for the lower yield could lie in the strong infestation with *Cercospora resedae*. Further field trials will

FIGURE 1. Dry matter yield of Weld (*Reseda luteola* L.) grown at Glinzendorf and at Dörfles.



have to be done to test whether the differences in yield will become less extreme under better growing conditions.

At both sites, the Dyer's Chamomile provenances (Figure 2, Figure 3) 'Artern' and 'TLL' showed significantly higher dry matter yields of flower heads than the provenance 'Wies'. In Dörfles, the dry matter yields of all provenances were slightly higher than in Glinzendorf. The dry matter yields ranged between 1.1 and 1.8 t ha^{-1} and were much lower than the dry matter yield of 2-2.5 t ha^{-1} achieved by conventional farming methods in Thüringen (TLL, 1997). Further testing will determine whether the yields are higher in the second cultivation year (Dyer's Chamomile can be cultivated for at least two years).

The dry matter yields (first + second harvest, whole plant) of Dyer's Knotweed (Figure 4, Figure 5) did not vary statistically significantly between the three provenances. In Glinzendorf, the dry matter yields were on average 7.5 t/ha, in Dörfles 7.7 t ha^{-1}. There is no current literature available with data concerning dry matter yields of whole plants. Data available are on leaf dry matter yield (because only the leaves contain indigo) and fresh weight (because Dyer's Knotweed has to be processed immediately after the harvesting, without drying, fresh weight data are more relevant in practice).

The fresh weight (first + second cutting) was on average about 38 t ha^{-1} (in Glinzendorf) and 34 t ha^{-1} (in Dörfles). Although fresh weight data cannot be compared directly because of the fast evaporation, the

FIGURE 2. Dry matter yield of Dyer's Chamomile (*Anthemis tinctoria* L.) grown with three provenances (Artern, TLL, Wies) at Glinzendorf.

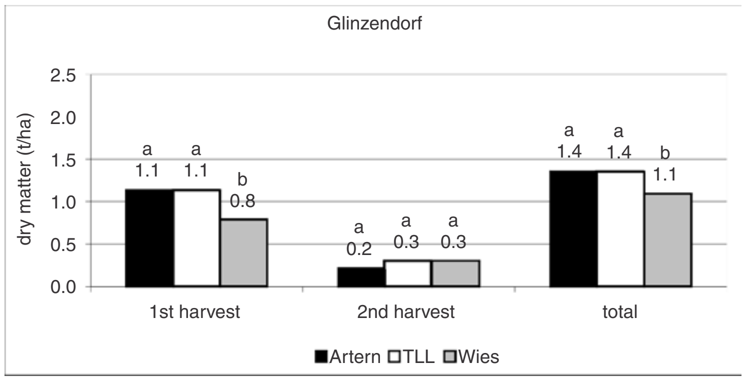
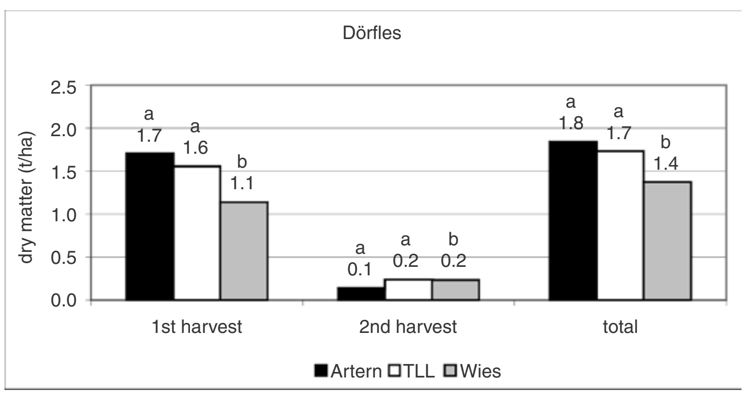


FIGURE 3. Dry matter yield of Dyer's Chamomile (*Anthemis tinctoria* L.) grown with three provenances (Artern, TLL, Wies) at Dörfles.



fresh weight data of both sites are in a higher range than the 20-30 t ha^{-1} fresh weight from cultivation by conventional farming methods in Thüringen (TLL, 1999).

The leaf dry matter yield of Dyer's Knotweed (first + second cutting) was at both sites on average 3.1 t ha^{-1}. There were no significant differences between the three seed provenances tested. The average lies in the range of the 2.3-3.9 t ha^{-1} achieved in Thüringen under the conditions prescribed by conventional farming (Biertümpfel & Vetter 1999).

FIGURE 4. Dry matter yield of Dyer's Knotweed (*Polygonum tinctorium* Ait.) grown with three provenances (TLL, Furusho, Ono) at Glinzendorf.

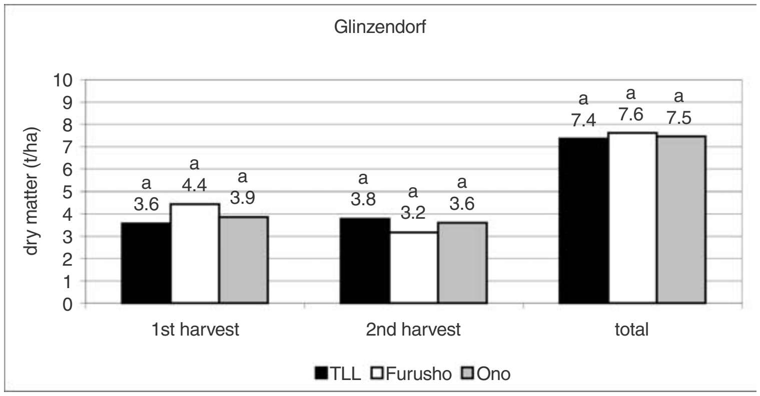
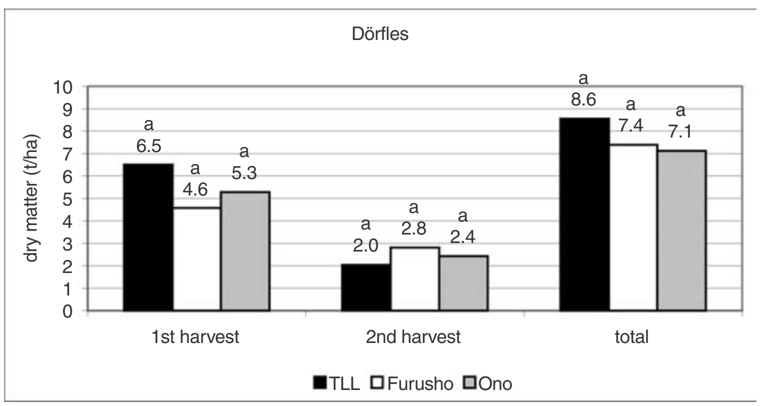


FIGURE 5. Dry matter yield of Dyer's Knotweed (*Polygonum tinctorium* Ait.) grown with three provenances (TLL, Furusho, Ono) at Dörfles.



Dyestuff Content

The dyestuff content of Weld (total flavonoid content) of the field trial samples ranged between 1.53-4.00% of the dry matter. The total flavonoid content of the commercially available samples ranged between 2.55-2.96%. Eight of the 12 field trial samples lay below the lowest content of the commercially available samples, however, four of the samples lay well above the highest content of the commercially available samples.

Dyestuff content of the samples lay in the range of the data of Thüringen (2-4%; TLL, 1999) and Brandenburg (2-3%, Adam & Dittmann, 1998).

It can only be determined by analysis of a large number of samples in further trials whether the dyestuff content can be improved under better conditions (no infestation with *Cercospora resedae*) and under modification of the harvesting method (higher cutting horizon). The influence of seed provenance on the dyestuff content has to be tested, as well. According to the results, which have not been proven statistically, the provenance with the highest dry matter yield in this field trial does not seem to have the highest dyestuff content.

The total flavonoid content of Dyer's Chamomile (calculated as quercetin) ranged between 0.84 and 1.50% of flower-head dry matter, which is below the dyestuff content of the commercially available samples (1.64-2.43%). It seems unrealistic that those dyestuff contents which are clearly below the data reported in relevant literature (4-5% according to Vetter et al., 1999 and 2.54-6.82% according to Biertümpfel & Vetter, 1999; both Thüringer Landesanstalt für Landwirtschaft) are only caused by different characteristics of sites and provenances (although even one provenance was provided by the Thüringer Landesanstalt). It is assumed that the differences are due to different analytical methods.

The indican content in fresh leaves of Dyer's Knotweed showed great differences according to the seed provenance. The German provenance had the lowest indican content at both cutting dates and at both sites 'TLL' (0.12-0.15% leaf fresh weight). The contents of the Japanese provenances 'Furusho' and 'Ono' were statistically significantly higher (the highest content was 0.38% of leaf fresh weight) (Figure 6, Figure 7). The indigo content (calculated by the content of indican in fresh leaves) ranged between 0.22-0.64% of leaf dry matter. Differences in the indigo content between the first and the second cutting, as reported by Yonekawa (1993), were not confirmed.

The dyestuff content of the tested samples is so far below the data in literature (2.06-6.37% leaf dry matter, Vetter et al., 1999; Biertümpfel & Vetter, 1999) that the cause cannot lie in different characteristics of sites but must be due to different extraction and analytical methods. To enable comparable results the development of standardized analytical methods is necessary.

FIGURE 6. Content of indican in % of fresh leaf matter of Dyer's Knotweed (*Polygonum tinctorium* Ait.) grown with three provenances (TLL, Furusho, Ono) at Glinzendorf.

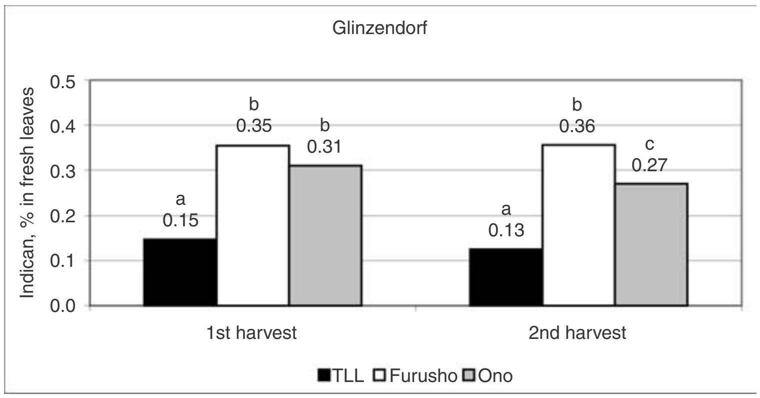
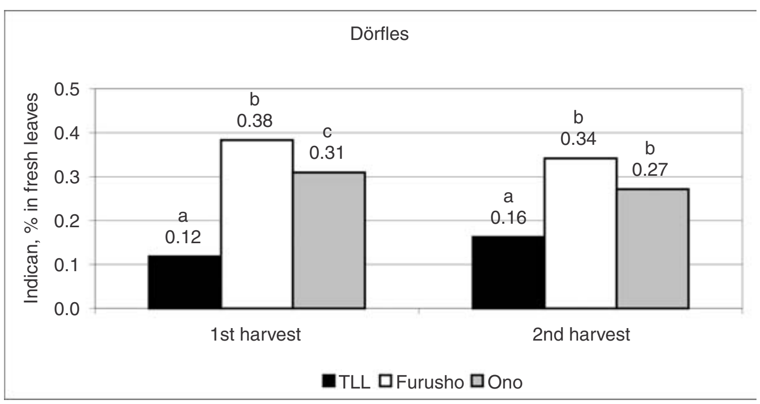


FIGURE 7. Content of indican in % of fresh leaf matter of Dyer's Knotweed (*Polygonum tinctorium* Ait.) grown with three provenances (TLL, Furusho, Ono) at Dörfles.



Dyeing Quality

Only a few differences were noticeable in the color shade of Weld when comparing the samples of the field trial to the commercially available samples. The fabric appearance of the dyeing was even, had no irregularities, and showed a dull brownish color. The differences in brightness between the samples were small. One of the commercially available samples showed an obviously pure, much more brilliant shade, which could also be seen in the remission diagram. It is assumed that this sample had been chemically pre-treated.

The fabric appearance of the dyeing with the samples of Dyer's Chamomile was even and had no irregularities. The color was a rich, dark green yellow shade. There were differences in the shades of the samples, but these differences were not so obvious as those occurring in Weld.

The samples of Dyer's Knotweed indigo showed an obviously different color shade. The colors of the samples from both sites of the German provenance 'TLL' were obviously lighter than the other provenances, which is due to the much lower content of indigo in this provenance, as confirmed by the indican analysis. Changes in shade among the samples tested were small. The lighter the dyeing, the greater was the tendency of the indigo to appear uneven in the fabric.

Differences in the general use fastness properties between the samples (light fastness, rub fastness, fastness to perspiration, wash fastness) of Weld, as well as the samples of Dyer's Chamomile, were hardly noticeable. The differences in the indigo dyeing were the result of differences in the depths of shade. In practice (depending on the product characteristics) most cases require grades of 3-4. These results show that good and very good fastness data can also be achieved with natural dyestuff, with the exception of the light fastness in Weld and Dyer's Chamomile. The light fastness grades of Weld (grade 2 and grade 2-3) and Dyer's Chamomile (grade 2, 2-3 and 3) were not satisfactory, while those of indigo dyeing were good or very good (grade 4 and 4-5).

CONCLUSIONS

With this paper we want to encourage further studies on the growing and processing of dye plants under the conditions prescribed by organic farming. Firstly, this assessment of yields and quality parameters of selected dye plants can serve as a reference of comparison for studies under the conditions set out by organic farming. Secondly, the detailed description of the methodology should facilitate further studies. Thirdly, results of this paper and of Hartl and Vogl (2000a) indicate various paths for research with potential for the development of a natural dying business with resources from organic farming.

At first glance, specialized, disciplinary technical research with the aim of raising yields or dyestuff output are necessary: research on the improvement of the organic cultivation of dye plants (organic fertilization, position in crop rotation, anti-phytophatological stability of the crop, etc.) and of the selection of appropriate provenances under conditions set out by organic farming will be helpful to achieve higher yields. A great potential for improvement of dyeing results is expected in the development of dyestuff extracts and the optimization of dyeing methods. For natural textiles, dyed with dyestuff from organic farming, professional marketing and economic research in this sector of organic farming are important.

However, it is simply not enough to improve yields at one end of the chain and/or to promote natural dyes with a "green" image at the other end. In addition to these specialized disciplinary approaches, we want to stress the need for a systemic, inter- and transdisciplinary look at the improvement along the whole chain of production, processing, and trade. It is necessary to establish pilot projects that provide a link between organic farmers, certified processors (extraction, dyeing, design), and organic trade. The flow of information from the market to the producer concerning consumer needs or quality parameters is weak and lacks professional spirit; the same can be said for the flow of information from the producer to the processor concerning technical requirements and/or limitations. The world wide web of "the natural dyeing business" has yet to be developed and linked with the multitude of local and regional initiatives.

NOTE

1. For example, purple made of truncated murex and cochineal made of cochineal insects (*Dactylopius cacti* L.) are still used today for coloring textiles and food (Hofmann, 1989).

REFERENCES

Adam, L. & Dittmann, B. 1998. Färberpflanzen: Färber-Resede (*Reseda luteola* L.)-Anbau, Ernte und Nachbehandlung. Extension leaflet, Landesanstalt für Landwirtschaft (ed.), Güterfelde, Germany.

Adam, L. & Dittmann B. 1999. Anbauversuche zu Färber-Resede und Krapp in Brandenburg. In *Proceedings Forum Färberpflanzen*, pp. 112-133, Fachagentur Nachwachsende Rohstoffe (ed.), Gülzow, Germany.

Adam, L., Dittmann B. & Meyer E. 1997. Erste Erfahrungen zum Anbau und zur Farbstoffgewinnung von Färber-Resede und Krapp im Land Brandenburg. In *Proceedings Gülzower Fachgespräche: Färberpflanzen-Forum Färberpflanzen*, pp. 62-73, 04 & 05 of June 1997, in Dornburg/Germany, Fachagentur Nachwachsende Rohstoffe (ed.), Gülzow, Germany.

Biertümpfel, A. & Vetter A. 1999. Züchterische Bearbeitung von Färberpflanzen. In *Proceedings Gülzower Fachgespräche: Färberpflanzen-Forum Färberpflanzen*, 02 & 03 of June 1999, in Dornburg/Germany, pp. 94-105, Fachagentur Nachwachsende Rohstoffe (ed), Gülzow, Germany.

Biertümpfel, A. 1997. Züchtungsergebnisse bei Färbepflanzen. In *Proceedings Gülzower Fachgespräche: Färberpflanzen-Forum Färberpflanzen*, 04 & 05 of June 1997, in Dornburg/Germany, pp. 88-98, Fachagentur Nachwachsende Rohstoffe (ed.), Gülzow, Germany.

Biertümpfel, A., Wurl, A. Vetter & Bochmann R. 2000. Anbau von Färberpflanzen zur Gewinnung von Farbstoffextrakten für die Applikation auf Textilmaterial. *Berichte über Landwirtschaft*, *78*, 402-420.

BMLF 1975. Österreichische Bodenkartierung, Kartierungsbereich Gänserndorf, KB 27. Ministry of Agriculture, Forestry, Environment and Water Management, Vienna, Austria.

Bochmann, R. & Weiser M. 1999. Applikation von Pflanzenfarben auf Leinen und Wolle. In *Proceedings Gülzower Fachgespräche: Färberpflanzen-Forum Färberpflanzen*, 02 & 03 of June 1999, in Dornburg/Germany, pp. 187-208, Fachagentur Nachwachsende Rohstoffe (ed.), Gülzow, Germany.

Dachler, M. & Pelzmann H. 1989. *Heil-und Gewürzpflanzen. Anbau-Ernte-Aufbereitung*. Österreichischer Agrarverlag, Vienna, Austria.

Hartl, A. & Vogl C.R. 2000a. Faser-und Färbepflanzen aus Ökologischem Landbau. Erzeugung, Verarbeitung und Vermarktung. Endbericht zum Forschungsprojekt L 1043/96 (Erarbeitung von Grundlageninformationen und Strategien zu Erzeugung, Verarbeitung und Vermarktung von Faser-und Färbepflanzen aus Ökologischem Landbau). Project L 1043/96, Ministry of Agriculture, Forestry, Environment and Water Management & Ministry for Education, Science and Research. Vienna, Austria.

Hartl, A. & Vogl C.R. 2000b. Faser-und Färbepflanzen aus Ökologischem Landbau. Anbauversuche Fasernessel. Endbericht zur Projekterweiterung Teil A (Ertragsleistung, Fasergehalt und Faserqualität von fünf Fasernesselklonen auf einem Biobetrieb in Niederösterreich). Project L 1043/96, Ministry of Agriculture, Forestry, Environment and Water Management & Ministry for Education, Science and Research. Vienna, Austria.

Hartl, A. & Vogl C.R. 2000c. Faser-und Färbepflanzen aus Ökologischem Landbau. Anbauversuche Färbepflanzen. Endbericht zur Projekterweiterung Teil B (Ertragsleistung und Farbstoffgehalt von Färber-Resede (*Reseda luteola* L.), Färberkamille (*Anthemis tinctoria* L.) und Färberknöterich (*Polygonum tinctorium* Ait.) auf Biobetrieben in Niederösterreich im Vergleich mit praxis-und handelsüblichen Warenpartien). Project L 1043/96, Ministry of Agriculture, Forestry, Environment and Water Management and Environment & Ministry for Education, Science and Research. Vienna, Austria.

Hartl, A. 1997. Untersuchung des Potential zur Herstellung von Naturtextilien aus heimischen Faser-und Färbepflanzen aus Ökologischem Landbau. Diploma Thesis, University of Agricultural Sciences, Vienna, Austria.

Hill, D.J. 1993. Production of natural indigo in the UK. Department of Continuing Education, University of Bristol. Manuscript. In *Proceedings Waidtagung* 1992, Nr. 4/5, pp. 23-26, Arnstadt, Thüringer Chronik-Verlag, H.E. Müllerott, Germany.

Hofmann, R. 1989. Färbepflanzen.-Dissertation at the University of Vienna, Austria.

Kaiser, R. 1993. Quantitative Analysis of Flavonoids in Yellow Dye Plant Species Weld (*Reseda luteola* L.) and Sawwort (*Serratula tinctoria* L.). In: *Angewandte Botanik 67*, 128-131.

Meyer, U. 1997. *Farbstoffe aus der Natur*. Katalyse Institut (ed.), Die Werkstatt, Göttingen, Germany.

Munzert, M. 1992. *Einführung in das pflanzenbauliche Versuchswesen*. Parey, Hamburg, Germany.

Nultsch, W. 1986. *Allgemeine Botanik*. Kurzes Lehrbuch für Mediziner und Naturwissenschaftler. 8. ed. Georg-Thieme Verlag, Stuttgart, Germany.

Roth, L., Kormann K. & Schweppe H. 1992. *Färbepflanzen, Pflanzenfarben: Botanik, Färbemethoden, Analytik, türkische Teppiche und ihre Motive*. Ecomed, -Landsberg/Lech, Germany.

Schellenberg, I., Schnüber G. & Kabrot K. 1999. Biotechnologische Verfahren zur Erzeugung von Pflanzenmaterial aus Rhababer als Voraussetzung für die groβtechnische Isolierung. In *Proceedings Gülzower Fachgespräche: Färberpflanzen-Forum Färberpflanzen*, 02 & 03 of June 1999, in Dornburg/Germany, pp. 106-111, Fachagentur Nachwachsende Rohstoffe (ed.), Gülzow, Germany.

Schweppe, H. 1992. *Handbuch der Naturfarbstoffe: Vorkommen, Verwendung, Nachweis*. Ecomed, Landsberg/Lech, Germany.

TLL 1997. Anbautelegramme zu Färberhundskamille, Färberknöterich, Färberwau, Kanadische Goldrute, Krapp, Saflor und Waid. Thüringer Landesanstalt für Landwirtschaft eds., Jena, Germany.

TLL 1999. Anbautelegramme zu Färberknöterich (*Polygonum tinctorium*), Färberwau (*Reseda luteola*), Kanadische Goldrute (*Solidago canadensis*) und Waid (*Isatis tinctoria*). ed.: Thüringer Landesanstalt für Landwirtschaft eds., Jena, Germany.

Vetter, A. 1994. Probleme und Lösungsansätze für die Entwicklung von Anbauregimen für Färbepflanzen am Beispiel des Waids.-In *Proceeding 6. Thüringer Waidtagung*., pp. 44-50, Pferdinsleben, 13. Nov.1993, Förderkreis Gartenbaumuseum Cyriaksburg eds., Erfurth, Germany.

Vetter, A. 1997. Potentielle Pflanzen zur Gewinnung von Naturfarbstoffen-Bedeutung und Markt. In *Proceedings Gülzower Fachgespräche: Färberpflanzen-Forum Färberpflanzen*, 04 & 05 of June 1997, Dornburg, pp. 21-38, Fachagentur Nachwachsende Rohstoffe (ed.), Gülzow, Germany.

Vetter, A., Schwabe I. & Biertümpfel A. 1999. Ergebnisse zum Anbau und zur Erstverarbeitung von Färbepflanzen. In *Proceedings Gülzower Fachgespräche: Färberpflanzen-Forum Färberpflanzen*, 02 & 03 of June 1999, in Dornburg/Germany, pp. 68-82, Fachagentur Nachwachsende Rohstoffe (ed.), Gülzow, Germany.

Wagner, F. & Prediger G. eds. 1990. *Der Feldversuch*. Durchführung und Technik. Schlüchtern-Herolz: Selbstverlag F. Wagner, Germany.

Wurl, G. 1997. Ergebnisse von Anbauversuchen aussichtsreicher Färbepflanzen.-In *Proceedings Gülzower Fachgespräche: Färberpflanzen-Forum Färberpflanzen*, 04. & 05. 06. 1997 in Dornburg. Fachagentur Nachwachsende Rohstoffe ed., Gülzow. S., pp. 47-61.

Wurl, G., Schwabe I. & Hill D. 1999. Gewinnung von Indigo aus Waid und Färberknöterich. Unpublished paper, Forum Färberpflanzen 1999, Dornburg, Germany.

Yonekawa, T. 1993. Ai, the Japanese Natural Indigo Dye; its Present and Future Challenges. In *International Woad Conference* in Erfurth, pp. 18-21, nr. 4/5, part 2 & part 3. Arnstadt, Germany.

ZAMG 1999. Federal Service for Meteorology and Geodynamics, Vienna, Austria.

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