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Review of recent research on navy beans (*Phaseolus vulgaris*) in the United Kingdom

BY R. C. HARDWICK
Institute of Horticultural Research, Wellesbourne, Warwick CV35 9EF, UK

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SUMMARY

Navy beans are the raw material for 'baked beans'. Since the 1960's a number of workers have attempted to introduce the crop to the United Kingdom. The paper reviews the results of research to date.

In favoured areas of the United Kingdom yields of 300 g seed/m^2 may be expected in small-plot trials. The optimum plant spacing is between 20 and 30 plants/m^2 and dressings of about 150 kg/ha of N fertiliser are required for maximal yield. The nitrogen fertiliser may be dispensed with, at the cost of a small reduction in yield, if the seed is inoculated with an elite strain of *Rhizobium phaseoli.*

In the United Kingdom the potential diseases of the crop include halo-blight (*Pseudomonas syringae* pv. *phaseolicola*), bean common mosaic virus, and anthracnose (*Colletotrichum lindemuthianum*). Genetic sources of resistance have been identified, and they are incorporated in some of the UK-bred material.

It seems likely that the varieties with improved adaptation and disease resistance that are now available from the UK work will be useful to farmers in continental Europe. For the UK itself, some improvements in cold-tolerance and yield stability may still be required.

The paper concludes with a discussion of the lessons to be learned from the project.

INTRODUCTION

'Navy' beans (syn. pea beans), originally known as navy peas (Reddick, 1928; Steinmetz & Arny, 1932), are varieties of *Phaseolus vulgaris* with round white seeds in the size range from about 180 to 240 mg/seed. The United Kingdom imports 90 000 tonnes of navy beans/year (Reid, 1979), most of which are consumed as 'baked' beans. In volume terms baked beans are the United Kingdom's most important canned food, and the second most important vegetable after potatoes (Anon., 1987*c*). Four and half million cans of baked beans are consumed daily in the UK (Bench, 1981). At present the entire UK requirement of navy beans is imported, mostly from Michigan and Ontario. This paper reviews efforts over the last 25 years to establish navy beans as a farm crop in the United Kingdom. Previous reviews in this area include Evans & Davis (1978) on the breeding work and Hardwick (1983) on physiology. The history of the Michigan breeding programme is recounted by Andersen (1983).

'French', 'dwarf' or 'green' beans, varieties of *Phaseolus vulgaris* that are grown for their green fleshy pods, are widely grown in gardens in the United Kingdom and are an established commercial crop in eastern England. 'Dry', 'haricot' or 'navy' beans were investigated at the Horticulture Research Station, University of Cambridge, between 1930 and 1942 (laboratory notebooks and unpublished reports of D. Boyes, deposited at the Institute of Horticultural

Research, Wellesbourne) and were grown by farmers in Cambridgeshire and Essex for a short time during the Second World War (Anon., 1940*a*, *b*; St Clair Feilden, 1944) and they are still grown by some gardeners. The first varieties of navy beans had an indeterminate growth habit and produced long 'viney' plants. Modern varieties have a dwarf determinate habit, traceable to an ancestor obtained in the 1940's by X-ray mutagenesis (Down & Andersen, 1956) which was subsequently used in breeding programmes at Michigan State University and elsewhere. Almost all currently available varieties of navy bean were bred in north America.

In 1968 the official document on possibilities for import substitution in agriculture made no mention of navy beans (Anon., 1968). Commercial interest in the crop was stimulated by a 50% increase in the price of imported beans in 1969 - 1970 (Innes & Hardwick, 1974; Scarisbrick, Clewer & Wilkes, 1978). A closed conference on navy beans was held by the Pea Growing Research Organisation (PGRO) near Ipswich on 24 November 1971, with a second a year later (Anon., 1972*a*, 1973*a*). In 1972 eleven crops were grown in the UK ranging in extent from 1 to 10 ha (Anon., 1973*c*), in 1973 80 ha were grown, and in 1974 500 ha (Evans, 1974*b*; Scarisbrick, Carr & Wilkes, 1976). Research on *P. vulgaris* as a source of protein for animal feed had begun at Cambridge in the early 1960's (Froussios, 1970; Evans, 1974*b*; Evans, Hamblin & Davis, 1974; see also Evans & Gridley, 1979; Gridley & Evans, 1979), and by 1974 experiments and trials on navy beans were in progress at Cambridge, at PGRO, at the National Vegetable Research Station (NVRS) and at Efford (Tuckwell, 1974). But in the very cool summer of 1975 growth was poor and harvesting conditions so difficult that almost the entire crop was ploughed in. Thereafter commercial interest in the navy bean waned (Cutting, 1975; Scarisbrick, 1976) but research continued (Fig. 1). The first British-bred variety of navy bean entered the National List in 1978 (Gent & Bingham, 1977; Gent, 1981)

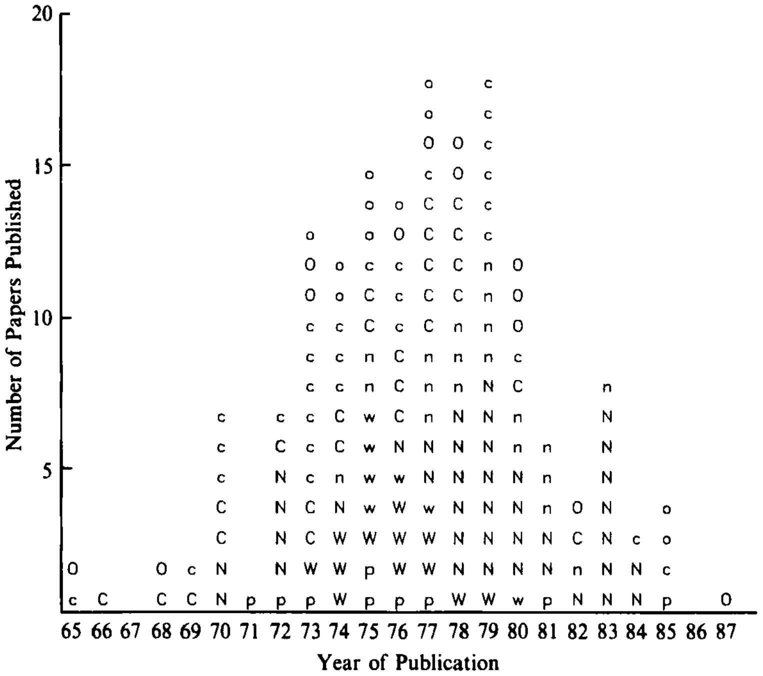

Fig. 1. UK published work on navy beans 1965-1987, showing the total numbers of papers published each year and their origin and type: Cc = from Cambridge University, Nn = NVRS, Pp = PGRO, Ww = Wye, Oo = other. Capitals = published in a refereed journal, lower case = other. Most, but not all, of the data used to construct this figure are reproduced as the Reference List.

and by 1986 finished varieties had been entered by two commercial breeders, by Cambridge University and by the NVRS. Movements in the prices of cereals in the mid-1980's led to a revival of interest in navy beans amongst farmers and in 1985 and 1986 there were farm-scale trials at a number of sites (Long, 1985; Anon., 1986; Gent, 1985; 1986). In November 1986 the price of imported navy beans suddenly increased almost threefold, from $27 to $70/100 lb, following disastrous rains in Michigan and Ontario, and interest in growing the crop in the UK was further increased (Young, 1986; Heath, 1987; Long, 1987).

Most of the UK work on navy beans has been done by four organisations; (1) the Department of Agriculture (later the Department of Applied Biology), Cambridge University; (2) the Department of Agriculture, Wye College, University of London; (3) the Pea Growing Research Organisation, later Processors and Growers Research Organisation; (4) the National Vegetable Research Station, later Institute of Horticultural Research, Wellesbourne. Other groups who worked on the crop included the government Agricultural Development and Advisory Service, and the Universities of Southampton, Dundee and Bangor. In all, in the period 1960 – 1987, approximately 180 papers and reports on the agronomy, pathology and physiology of navy beans were published (Fig. 1).

AGRONOMY

Sowing date and location

Because it is sensitive to frost, *P. vulgaris* cannot be sown before early April, and sowings at that time may take almost 2 months to emerge (Hardwick, 1972). As the season progresses and soil temperatures increase emergence times decrease; at soil temperatures of 17 °C the crop emerges in 5 days (Scarisbrick *et al.*, 1976). The variation in the rate of emergence of *P. vulgaris* with temperature can be used to detect small differences in temperature between different fields on the same farm (Hardwick, 1972). The rate of growth in length of the axis has a smaller Q_{10} than does the rate of growth in weight. Hence, since the length of the axis at emergence is fixed, the weight of the plant axis at emergence increases as soil temperature increases (Hardwick, 1978). Low temperatures before emergence also adversely affect the rate of growth in weight after emergence (Hardwick, 1972; Hardwick & Andrews, 1980*a*), and plant size at harvest (Scarisbrick & Carr, 1975), perhaps as a consequence of the depletion of reserves (Coolbear, Newell & Bryant, 1987). It has also been shown that the percentage of emergence increases with soil temperature (Scarisbrick & Wilkes, 1975; Scarisbrick *et al.*, 1976). For all these reasons sowings made in cool soils are likely to result in a worse plant stand and in smaller and slower growing seedlings than sowings made into warm soil. The suggestion (Leakey, 1975, 1982; Gent, 1985) that because navy beans are sown relatively late they could be double cropped after e.g. a spring-grazed crop of forage rye or forage brassica, does not appear to have been tested.

On the basis of studies in Michigan, Smucker & Mokma (1978) concluded that navy beans require 1000 accumulated day degrees above 10 °C to reach maturity. If they are right it would be impossible to grow navy beans in England; the average temperature sum during summer at Wellesbourne, for example, is only 718 accumulated day degrees above 10 °C (30-yr mean figure for the period 15 May to 30 September). However Smucker & Mokma's estimate appears to have been inflated by the inclusion of periods of very hot weather when temperatures exceeded the upper limit for growth; experience in this country suggests that the crop requires approximately 700 accumulated day degrees above 10 °C or 2000 Ontario Heat Units and that this is available in most years in southern England, provided that the crop is sown as early as possible, i.e. in mid-May (Scarisbrick *et al.*, 1976; Andrews, Hardwick & Hardaker, 1983). But in mid-May in this country soil temperatures are only 12 – 13 °C

(Hardwick, 1972). English navy bean crops are thus very likely to suffer the deleterious effects of cold seed beds mentioned above. The Michigan crop can be sown in mid- to late June, when soil temperatures are about 18 °C, and it therefore escapes these effects.

UK workers on other cold-sensitive crops have used meteorological records to identify suitable locations for e.g. grain maize (Scarisbrick & Carr, 1975) and outdoor tomatoes (Barrie & Gray, 1980). Their maps could probably also be used for navy beans. Navy beans have been trialled successfully as far north as Scotland (Hardwick, Hardaker & Innes, 1978), as indeed have green beans (North, Frith & Taylor, 1962), but the commercial acreage of green beans is limited to the southern and eastern counties of England, and the area suitable for navy beans is likely to be even more restricted; the ideal site will be a sheltered south facing slope on a light sandy loam, and not more than 120 m above sea level (A. Shirlin, personal communication).

Plant population and row width

In north America the recommended density for navy beans is 20 – 30 plants/m^2 (Mclaren & Littlejohn, 1975). A similar density appears to be optimal for the UK (Scarisbrick & Carr, 1975). The relationship between yield and density in *P. vulgaris* follows the familiar diminishing returns form of response (Andrews & Hardwick, 1981) but detailed studies through the growing season reveal (Jones, 1967) that at the beginning and at the end of growth close-spaced plants have unexpectedly high rates of growth. The early season effect was attributed to co-operative or mutual protection effects which were greater between close- than between wide-spaced plants (Jones, 1967). The reason for higher than expected growth rates in close-spaced plants during pod fill (Jones, 1967) is less well understood. It has been observed by other workers (Hardwick & Andrews, 1983) and a recent account of a laboratory experiment (Clifford, Offler & Patrick, 1987) confirms that the coupling between pod growth and leaf area is not as strong in *Phaseolus* as in some other crops – in this case a tenfold reduction in leaf area (from 5 to 0·5 leaflets/experimental plant) was accompanied by less than twofold reduction in yield (from 2·3 to 1·3 g seed/plant). The response of yield to spacing is usually explained in terms of an effect of spacing on the size of the 'source'. The evidence from *Phaseolus* is that there is also an effect on the size of the potential 'sink' (see also Lucas & Milbourn, 1979).

The standard row spacing in Michigan is 71 cm (28 inches) (Erdmann & Adams, 1978). Plants grown in narrow rows and at high densities tend to mature more evenly and to give a better sample (Anon., 1973*b*; 1976*e*). This appears to be due to the suppression of axillary branches at high plant densities (Jones, 1967). The development of axillary buds and branches varies between varieties; this may account for varietal differences in response to density (Evans, 1972). Bud development is sensitive to ambient temperature (Andrews & Hardwick, 1981) and this may account for variation in the response to density between seasons.

Fertiliser nitrogen

In the United Kingdom little or no nitrogenous fertiliser is used on *Pisum, Vicia* and other legumes, yet substantial quantities are advised for green beans and trials with navy beans suggested that as much as 240 kg N/ha was required for maximum yields (Anon., 1973*e*; Nutman, 1974; Wilkes & Scarisbrick, 1974; King & Handley, 1976*b*; Anon., 1975*b*; Anon., 1976*b*, *c*. However, crops of navy beans on some sites, notably the University farm at Cambridge, develop consistent and heavy levels of nodulation and these crops show little or no response to nitrogen fertiliser (Evans, 1974*b*). Two strains of *Rhizobium phaseoli* were isolated from the Cambridge farm (Rothamsted collection numbers 3605 and 3607) and these and others have been the subject of trials by a number of workers (see the general review by Sprent

(1982)). Though some workers have reported no response of yield to inoculation (Anon., 1976*d*; Knott, 1976; Scarisbrick, Olufajo & Daniels, 1982) it seems likely that these reflect some failure of technique; the consensus is that inoculation of navy beans with an elite strain of *Rhizobium* (e.g. Rothamsted strains 3622 and 3644) gives substantial yield increases (Taylor, Day & Dudley, 1983), equivalent to that obtained from 90 kg fertiliser N/ha (Dart, Day, Eaglesham & Nutman, 1975) or from between 70 to 105 kg fertiliser N/ha according to season (Taylor *et al.*, 1983; see also Leakey & Day, 1977). The variation appears to be due to variation not in the performance of *Rhizobium* but in the effectiveness of fertiliser nitrogen. In wet summers nitrates are lost from the rooting zone by leaching and in such years the yields of crops inoculated with *Rhizobium* have equalled those of crops grown with the optimum dressing of fertiliser nitrogen. Inoculation with *Rhizobium* provides the plant with a supply of fixed nitrogen to the end of the growth period. The associated metabolic cost has not been determined.

Taylor *et al.*, (1983) found that 'fixation' (calculated as the difference in yield of Kjeldahl nitrogen in the seeds of inoculated plants and uninoculated controls) was substantially greater in late maturing varieties than in early (the figures were 93 and 38 kg N/ha respectively). This suggests that the plant and the bacterium take some time to establish an efficient symbiosis, and trials confirm that 'starter' dressings of 30 – 60 kg N/ha in the seedbed are required for maximum yields. This apparent inefficiency of the symbiosis early in the season prompted further work at Cambridge and NVRS. It was shown (Hardaker & Hardwick, 1978) that early nodule growth can be improved using fluid drilling techniques; i.e. sowing germinated seed with *Rhizobium* incorporated into the surrounding gel. However Taylor & Dudley (1978) subsequently found that the effects did not persist to the end of the season. The work at Cambridge led to the suggestion (Hamblin & Kent, 1973) that recognition, the earliest event in the establishment of the symbiosis, involves binding of the bacteria onto the root hairs by phytohaemagglutinins.

A theoretical calculation by Sinclair & de Wit (1975) suggested that species (such as *Phaseolus*) which produce seeds with a high protein content need to withdraw protein nitrogen from their leaves, because the roots cannot supply fixed nitrogen fast enough. The leaves then senesce and die, so setting a limit to yield. However, workers at NVRS observed that their germ-plasm collection contained a number of lines of *P. vulgaris* whose leaves did not senesce and die, but which remained green as the pods matured. Some simple experiments (Hardwick, 1979) suggested that growth substances were involved and this was confirmed by workers at Stirling University (Sexton, personal communication). The original observations on *Phaseolus* eventually led to an alternative explanation of leaf senescence patterns in legumes (Hardwick, 1983).

Harvesting the crop

With currently available varieties the seeds reach a moisture content of 20% or less, and are thus ready for combining (Scarisbrick & Carr, 1975) in good years in September, in bad years not before October (Scarisbrick *et al.*, 1976). Bipyridyl defoliants accelerate the rate at which the seeds dry (Anon. 1972*c*, 1973*d*; Hole & Hardwick, 1978) but this application has not as yet received clearance from the authorities, and as weather conditions deteriorate through September and October the percentage of stained and therefore unsaleable seed increases rapidly (Hole & Hardwick, 1978; Scarisbrick & Carr, 1975). Nonetheless the experience of commercially grown crops has been that quality has been entirely satisfactory (Gent, 1985). Beans are a fragile commodity, and they do not always move easily through augers and bucket flights, but in general the seed cleaning equipment that is used for processing peas can also be used for navy beans (Gent, 1986).

Three types of harvesting machinery have been used – combine plus cutter bar; combine plus stripper header; and combine plus pick up reel, preceded by an undercutting blade ('Levington torpedo') and swather (Anon., 1972*d*). In each case the combine drum is run very slowly and the concave opened wide, so as to minimise damage to the seed. The choice between these options depends on a balance of priorities – the need to reduce variable costs and to use only the available (arable) equipment has to be set against the need to reduce yield losses through seed spoilage and seed loss (Leakey, 1975). Substantial seed losses can occur in direct combining because of the 'shortness of straw' of most of the currently available varieties. In very dry climates seed losses can also occur through pod shatter; this is rarely a problem in the United Kingdom but is the reason why most American crops are undercut and picked up from the swath rather than direct combined. The problem of 'short straw' occurs because when raised at low temperatures the internodes of currently available varieties are very short. Attempts to overcome this problem by sprays of gibberellic acid failed (Anon., 1973*f*). 'Pod height' has been an important selection criterion in all the UK bean-breeding programmes and hence the new varieties should be more suited to direct combining (Gent & Lambert, 1981).

Yield

Farm yields in north America are of the order of 1·4 to 1·8 t/ha (Coyne, 1973; Arthey, 1974; Smittle & Williamson, 1976). Experiments and trials (summarised in Table 1) suggest that the yield potential of current varieties of *Phaseolus* in the UK is of the order of 300 g/m^2, i.e. (extrapolating) 3 t/ha. But in practice it has proved difficult to reach this potential; the PGRO survey of commercial farms (Anon., 1973*c*) found that yields varied from 2·9 t/ha down to 1·4 t/ha. The shortfall is partly systematic; farm crops generally tend to give smaller yields than small scale trials (Davidson & Martin, 1965; see also Gent, 1986). But there has also been proved to be extreme variability in performance between years. This is discussed in the section 'cold tolerance' below.

Quality

In nutritional terms, bean quality is a function of the quality and content of protein, and of the content of anti-nutritional factors. Protein content varies inversely with yield both within genotypes (Hardwick, 1979) and between them (Hamblin, 1973), but the genetic correlation is not high. The genetic range in protein content is from 20 to 34% (Woolfe & Hamblin, 1974; see also Evans & Gridley, 1979; Gridley & Evans, 1979; Polignano, 1982). Anti-nutritional factors in *Phaseolus* include haemagglutinins, anti-trypsins and flatulence factors (Evans, Pusztai, Watt & Baner, 1973; Carpenter & Woolfe, 1973). Haemagglutinins (lectins) and anti-trypsins are heat labile and destroyed on cooking – the flatulence factors are not. Genetic variation is available for flatulence factors (Murphy, 1973) and for lectin content (Pusztai, 1966), as it is for protein content, but 'quality' characters do not appear to have been used in the UK navy bean breeding programme, although some work was done on this at Cambridge (Cheah & Evans, 1973; Evans & Gridley, 1979; Gridley & Evans, 1979) in the context of a project sponsored by the Ministry of Overseas Development. In commercial terms the important quality characters for navy beans are visual appearance, cooking characteristics and taste. Visual appearance (size, whiteness, roundness) is strongly inherited and easily selected; cooking characteristics (measured in terms of 'mouth feel' and taste) are also inherited but are not easy to select for. A number of promising lines had to be discarded from the NVRS programme at the F8 and F9 stage after they failed a cooking test (Conway *et al.*, 1982).

Table 1. *Reported yields of navy beans in the United Kingdom*

Reference	Year of experiment	Variety	Density plants m^{-2}	Fertiliser NPK kg ha^{-1}	Yield g m^{-2}
Froussios (1970)	1965	3 Columbian varieties	29	—	398
Anon (1972*b*)	1971	4 Varieties	20–40	—	238–289
Hamblin & Evans (1976)	1971	6 Varieties	30	—	201
	1972	6 Varieties	30	—	147
	1973	6 Varieties	30	—	178
	1974	6 Varieties	30	—	341
Anon (1973*b*)	1972	Seafarer	40	—	237
			27	—	213
			20	—	257
			14	—	236
Scarisbrick & Wilkes (1973)	1972	Seafarer	43	168 112 56	202
Scarisbrick & Carr (1975)	1972–1974	Seafarer	32–38	—	386–538
Scarisbrick, Carr & Wilkes (1976)	1972–1974	Seafarer	—	168 112 56	295
Scarisbrick, Clewer & Wilkes (1978)	1972	Seafarer	43	168 112 56	224
	1973	Seafarer	54	168 112 56	379
	1974	Seafarer	48	168 112 56	269
	1975	Seafarer	48	168 112 56	275
	1976	Seafarer	48	168 112 56	243
Anon (1975*a*)	1973	Seafarer	19	—	210
			24	—	240
			34	—	235
			53	—	265
			80	—	205
Hamblin (1975)	1973–1974	7 Varieties	115	—	288
			12·8	—	232
Lucas & Milbourn (1976)	1973	Seafarer	20–80	168 112 56	293
	1974	Seafarer	25–100	168 112 56	351
Scarisbrick, Wilkes & Kempson (1977)	1973	Seafarer	21–38	168 112 56	375
	1974	Seafarer	21–38	168 112 56	357
	1975	Seafarer	15–44	168 112 56	278
Eaglesham & Dart (1974)	1974	Seafarer	—	240 0 0	229
Lucas, Milbourn & Taylor (1977)	1974	Seafarer	40	—	309
Davis & Evans (1975)	1975	Seafarer	51	—	208
Hardwick, Hardaker & Innes (1978)	1975	Seafarer	25	—	77–200
Hole & Hardwick (1978)	1975	Seafarer	39	—	118–175
Hardwick & Andrews (1980*b*)	1976	48 F4 Families	44	90 250 250	167–333 Cool–Warm
Bingham & Gent (1977)	1977	Seafarer	—	—	104
Andrews & Hardwick (1981)	1978	Seafarer	44	—	113
	1979	Seafarer	44	—	344
	1974	Seafarer	21–38	168 112 56	357
Andrews, Hardwick & Hardaker (1983)	1978	Seafarer	44	100 100 100	119
	1979	Seafarer	44	100 100 100	361
	1980	Seafarer	44	100 100 100	260
Taylor, Day & Dudley (1983)	1979	Seafarer	25–30	0 250 250 *R. Phaseoli* Strain 963 A	202
Conway, Hardwick, Innes, Taylor & Walkey (1982)	1981	Seafarer	50	—	298
Hardwick & Andrews (1983)	1981	Prelude	35	100 100 120 (and 120 topdress N)	340

PATHOLOGY

Virus diseases

There are two potentially serious virus diseases of *Phaseolus* in the United Kingdom; bean common mosaic virus and bean yellow mosaic virus. Both are caused by 760 nm rod potyviruses, and both are transmitted by aphids in a non-persistent manner. Bean common mosaic virus (BCMV) is a serious disease, capable of wiping out susceptible genotypes. The disease is transmitted via infected seed (Walkey, 1985). BCMV is rarely seen in commercial green or runner bean crops in the UK because most of the commercial varieties of green bean, and all varieties of runner bean, carry genetic resistance to most strains of BCMV (Walkey & Cooper, 1974). Analysis of this resistance reveals a complicated situation. The BCMV virus has four genes for virulence to *P. vulgaris*, while *P. vulgaris* has seven genes for resistance to BCMV (Drijfhout, 1978). The resistance genes comprise a necrosis gene 'I', five strain-specific genes 'bc' at three loci (bc-1 and bc-1^2; bc-2 and bc-2^2; bc-3 in Drijfhout's (1978) terminology), and a complementary, strain non-specific gene (bc-u). These give 12 resistance phenotypes. The virus' four genes are in gene-for-gene relationship with four of the host's strain-specific genes; the fifth of the resistance genes has not yet been overcome by any strain of the virus; thus *Phaseolus* varieties Valja and 1750 73 are resistant to all known strains of BCMV including the virulent NL3 strain (Walkey & Innes, 1978). The resistance conferred by the 'I' gene is due to a hypersensitive reaction. At temperatures above about 30 °C this resistance tends to break down with the production of 'black-root' symptoms. The phenomenon is only observed rarely in the UK.

The NVRS workers took the view that a UK navy bean would need BCMV resistance (Walkey & Innes, 1979; Innes & Walkey, 1980), and this comprehensive resistance was incorporated in the NVRS breeding programme, resistant segregants being identified by challenging with BCMV strains NL3 and NL4 (which between them carry all the known pathogenicity genes) in each generation (Conway *et al.*, 1982).

The Cambridge workers adopted a different approach; their material was not explicitly tested for BCMV resistance, but neither was BCMV infection eliminated from their breeding material. The result was that there were outbreaks of BCMV in the field almost every year at Cambridge, and this exerted strong selection pressure for resistance on the breeding lines. However, the genetic nature of the resistance is not known.

Bean yellow mosaic virus is not seed transmitted; it has a relatively wide host range and overwinters in perennials such as gladioli, clovers and lucerne. This virus has not yet proved a serious problem in *Phaseolus* in the United Kingdom, but problems might develop if susceptible varieties of *P. vulgaris* were to be grown on a large scale. There is genotypic variation in the susceptibility of beans to BYMV (Evans & Davis, 1978; Walkey & Innes, 1978) and major new sources of resistance have been identified at Wellesbourne (Walkey & Taylor, 1979; Walkey, Innes & Miller, 1983). These have been shown to confer high levels of resistance to seven world-wide isolates of the virus. The genetic basis of the resistance is not known and strain relationships have yet to be worked out. Resistance to bean yellow mosaic virus has not yet been used in a breeding programme.

Bacterial diseases

In the 1960's growers of green beans in the United Kingdom suffered substantial financial losses due to the disease halo-blight, caused by the bacterium *Pseudomonas syringae* pv. *phaseolicola*. The disease can kill susceptible genotypes, and crops with more than a certain level of visible infection are not acceptable for processing and have to be ploughed in. At Wellesbourne J. D. Taylor and colleagues showed that levels of infection in the green bean crop can be kept within the levels tolerated by processors by seed-crop hygiene, backed up by seed-testing (Taylor, 1970*a, b*), by chemical seed treatments (Taylor & Dudley, 1977*a, b*), or by chemical sprays (Taylor, 1972; Taylor & Dudley, 1977*a*). None of these eliminates the bacterium completely and the effectiveness of any given measure depends on epidemiological factors, particularly the rate of spread (Taylor, Phelps & Dudley, 1979). The bacterium does not survive overwinter in the United Kingdom; it enters the crop in infected seed and spreaads by rain-splash (Taylor, 1970*a*; Taylor, Dudley & Presly, 1979). Since chemical control is expensive, and not completely effective, control of seed infection by seed-crop hygiene is particularly important. To eliminate rain-spread infection it is necessary to raise seed crops in an arid climate with furrow irrigation and strict roguing of any infected seedlings. This is impossible in the United Kingdom and hence it is likely that any susceptible variety of navy bean that was grown year on year would sooner or later become infected. Many bean breeders, including both the Cambridge and the NVRS teams, have therefore sought to include genetic sources of resistance to halo blight in their programmes.

There are four races of halo blight, two of which (races 1 and 2) occur fairly commonly in the United Kingdom. The other two were discovered recently, and are known only from Africa (Davis, Taylor & Teverson, 1986; Taylor & Teverson, 1986). Resistance to race 1 of halo blight is available in the cv. Red Mexican U13 and a number of other cultivars, such as Rona and Cornell 42 - 242. This resistance is due to a single dominant gene. It is race-specific and does not confer resistance to race 2. Race non-specific resistance which is effective against at least race 1 and race 2 was found in lines PI 150414, GN Nebraska No 1 sel 27, and OSU 10183 (Russell, 1976*a*; Taylor *et al.*, 1978). The resistance of PI 150414 and GN Nebraska No 1 sel 27 to halo blight is due to a single gene whose expression varies from recessive to partially dominant depending on the genetic background (this accounts for some of the confusion in the literature (Taylor, Innes, Dudley & Griffiths, 1978)). Two lines of *P. vulgaris*, V4508 and V4604, with some resistance to race 1 and to race 2, i.e. to all the then known races of halo blight, were discovered in a survey of the Cambridge collection by Russell (1976*a*). Innes, Conway & Taylor (1984), working at NVRS, demonstrated that the partial (V4604) or low level resistance (V4508) was polygenic and that V4604 also possessed the Red Mexican gene for resistance to race 1. It is not clear whether this resistance has been used in any breeding programme. Resistance derived from PI 150414 was incorporated in the NVRS navy bean breeding programme (Conway *et al.*, 1982). The resistance of OSU 10183 is multigenic; it might be possible to obtain superior resistance by 'pyramiding' these genes (Conway *et al.*, 1982), but this has not yet been undertaken. OSU 10183 itself grows very poorly in UK conditions, producing a stunted plant (Conway *et al.*, 1982).

Other diseases

Other diseases which have been encountered in the UK include anthracnose (*Colletotrichum lindemuthianum*), foot-rot (*Fusarium* spp.) and *Botrytis* spp. PGRO showed that *Botrytis* can be controlled by the chemical benomyl (Anon., 1972*e*). Extensive work on anthracnose has been undertaken in France (Bannerot, Derieux & Fouilloux, 1971; Fouilloux, 1979). Until 1973 the resistance conferred by the dominant 'Are' gene was good against all known races of anthracnose - it was then overcome by four pathotypes (Fouilloux, 1979). In the United Kingdom Bailey (1974) studied some aspects of phytoalexin production in plants infected with *Colletotrichum*, and Richardson & Evans (1972) sought resistance to *Colletotrichum*. The NVRS workers showed that their selections were resistant to the lambda race (Conway *et al.*, 1982). There appears to have been little other work on the disease in this country until recently, when workers at Long Ashton began work on the biochemical and molecular basis of resistance (Showalter *et al.*, 1985; Bailey, 1987). Some aspects of the biology of *Fusarium* on *Phaseolus* were studied by Russell (1976*b*), Clarkson (1978) and Russell & Mussa (1977*a, b*). Foot rot diseases are a major problem in dry bean crops in north America; in the green bean growing areas of this country foot rot is not a problem, probably because the disease has been controlled by good husbandry and long rotations.

Weeds and pests

Most of the published work on herbicides for *P. vulgaris* (e.g. Roberts & Hewson, 1970; Roberts, Bond & Ricketts, 1974; Roberts & Bond, 1984) used varieties of green beans but it is relevant to navy beans as well. Some farmers have tried steerage hoes but the majority of farm crops and trials have used a mixture of pre- and post-emergence herbicides and these have given good control of most weed species (Anon., 1976*a*; King & Handley, 1976*a*). However, late germinating plants of *Chenopodium, Solanum* and *Matricaria* do tend to escape and they can cause problems at harvest. Navy beans do not appear to have encountered any major problems from animal pests in the UK. McWalter (1964) at Cambridge (cited by Froussios, 1970) showed that varieties of *P. vulgaris* differed in their susceptibility to aphid attack, depending on the hairiness of their leaves. Other pests that have been encountered include weevil (Coleoptera; *Sitona lineatus*), cutworm (Lepidoptera; Noctuidae) and bean seed fly (Diptera; *Delia platura* – see Anon., 1976*f*). There has been little work in the United Kingdom on any of these as potential pests of navy beans.

PHYSIOLOGY

Cold tolerance

Most of the large scale trials of navy bean in the UK have used cultivars that were bred in north America. Performance was erratic and yields unreliable (Gent, 1985). That *Phaseolus vulgaris* is sensitive to low temperatures throughout the life cycle was already known (Arthey, 1974) and is hardly surprising; the centre of diversity of the species is in subtropical central and south America, where temperatures are likely to be substantially above those of the United Kingdom. The mean summer (15 May to 30 September) temperature at NVRS, for example, is 15·2 °C. In controlled environments relative growth rates of various varieties of green beans decline sharply between 20 °C and 14 °C, with a Q_{10} of about 3·3 (Austin & Maclean, 1972), and an optimum of approximately 20°-25 °C (Jones, 1971). Laboratory experiments show that plants that have been raised at low temperatures not only have lower net assimilation rates, leaf extension rates and relative growth rates (Austin & Maclean, 1972), they also produce smaller plants – for example, the growth of lateral buds is suppressed at low (15°) temperatures (Andrews & Hardwick, 1981). It is likely that similar effects occur in the field. In south America yields of dry beans varied between sites according to site mean temperature, decreasing strongly as site mean temperatures decreased from 25 °C to 18 °C to 13 °C (Laing, Kretchmer, Zuluaga & Jones, 1982). In the United Kingdom the best available set of data from multiple sites is an 8 variety × 6 site trial of navy beans with sites from southern England to Scotland. There was no significant correlation between mean temperature and yield. The reason seems to be that the trial was conducted in a year in which there was only a small range of temperatures between sites (Hardwick *et al.*, 1978). Other experiments have confirmed that treatments which were designed to increase ambient temperature e.g. using shelter fences, painting the ground black and using clear Polythene mulch, resulted in substantial increases in yields of dry beans (Hardwick & Andrews, 1980*b*); indeed some advisers have suggested that Polythene mulches or covers should be used on commercial crops of navy beans (Anon., 1985). An alternative would be to find a genetic source of cold tolerance.

The extent of genotypic variation for 'cold tolerance' was investigated in the early years of both the Cambridge and the NVRS projects (McWalter, 1964; Austin & Maclean 1972).

Substantial genotypic variation was found in simple parameters, for example the minimum temperature for germination, or the response of time-to-emergence to soil temperature and this led to a considerable body of work on the physiology of temperature effects, and on genotype-temperature interactions, in *Phaseolus*. The UK and world literature on cold-tolerance in *Phaseolus vulgaris* was reviewed by Hardwick (1983).

Superior parental material was selected at NVRS (using cold tolerance tests in the laboratory) and at Cambridge (by field trials) and used in breeding programmes. The NVRS parental material was shown to be superior to the standard Michigan cv. Seafarer both in mean yield, and in stability of yield over environments (Conway *et al.*, 1984; Andrews, Hardwick & Hardaker, 1983). This stability was associated with compensatory (rather than additive – see Hardwick & Andrews, 1980*c*) variation of yield components, suggesting that the stability was source- rather than sink-based (Andrews *et al.*, 1983). Methods of selecting in a segregating population for tolerance or resistance to pathogens are well established but there are as yet no satisfactory predictor variables for cold tolerance (Evans & Davis, 1978). The available tests are slow, varietal rankings for 'cold tolerance' differ according to the parameter measured, and the discrimination between genotypes is poor (see Guye, Vigh & Wilson, 1987). Only one parameter has been shown to have a genetic correlation from generation to generation with yield potential or yield stability. This parameter (surplus photosynthate production) is time-consuming and expensive to measure (Hardwick & Andrews, 1980*a, b*; see also Evans & Davis, 1978).

Subsequent work points to a number of sub-cellular and molecular processes which are involved in cold effects. These include the cold lability of proteins, the content of nuclear DNA (Grime, Shacklock & Band, 1985); chlorophyll fluorescence (Wilson, 1984); and the production of heat-shock proteins (Franks, 1983). There is an active programme of work in the UK using some of these approaches in breeding or genetic manipulation for cold tolerance in pasture grasses and on *Zea*, (Anon., 1987*b*) but the UK work on cold tolerance in *Phaseolus* appears to have ceased.

PHYSIOLOGY – OTHER ATTRIBUTES

Flowering date

The first trials of *Phaseolus* germplasm at Cambridge revealed some south American cultivars with vigorous vegetative growth during summer, and which did not flower until the Autumn; this suggested that they were daylength sensitive (McWalter, 1964). Morgan and co-workers at Cambridge found that in these varieties flower buds are (unexpectedly) formed from mid-summer onwards but that in long days they absciss (Ojehomon, Rathjen & Morgan, 1968; Zehni & Morgan, 1976). They went on to show that the inhibitory effects of long days and the promotory effects of short days are perceived in the leaves and transmitted to the buds (Bentley, Morgan & Saad, 1975; Morgan & Zehni, 1980). The nature of the signal is not known but it seems that the balance between abscisic acid and cytokinin plays an important part in regulating progress along developmental pathways (Morgan & Morgan, 1984).

Morphology

Various morphological characters were closely studied by the Cambridge workers. The difference between 'dwarf' and 'climbing' phenotypes is due to a few major genes (the 'dwarf' Michigan varieties were obtained by X-ray mutagenesis of a long-internoded 'climbing' bean (Down & Anderson, 1956)), but the difference is not absolute; in many genotypes red light induces dwarfing growth, far-red induces climbing growth (Evans & Davis, 1978). Smartt (1970) showed that the difference between 'determinate' and 'indeterminate' growth habits is also genetically determined, the indeterminate character being dominant. Evans (1972) showed that the number of nodes to the first flower is determined by two additive genes each of which reduces nodes-to-first-flower by 2·5 nodes (4 days). 'Baldhead' or 'snakehead' seedlings are the result of mechanical damage to the dry seed. Workers at PGRO and at Cambridge showed (Anon., 1973*d*; Biddle, 1976; Evans & Davis, 1978) that some genetic sources of resistance to mechanical damage are available.

BREEDING

The PGRO ran trials of new varieties that had been bred overseas, and latterly in this country (Bingham & Gent, 1977, 1978; Gent & Bingham, 1978; Gent & Lambert, 1980, 1981; Anon., 1985). New varieties for the United Kingdom were produced by two teams, at Cambridge and at NVRS, and two private breeders (C. L. A. Leakey, and Sharpes of Sleaford Ltd). The work of the latter has not been written up but the parentages of the varieties bred by Leakey and by Sharpes Ltd are set out in their applications for Plant Variety Rights (see Table 2). The work at Cambridge up to the late 1970's has been described in detail by Evans & Davis (1978). After the early exploratory work by McWalter (1964) on cold tolerance, Ojehomon (1966) on the physiology of flowering, and Rathjen (1965) and Froussios (1970) on intraspecific differentiation, Evans and co-workers assembled a collection of 5000 accessions (Evans, 1974*b*; Evans & Walters, 1979) and began to investigate breeding methodology for *P. vulgaris*, using techniques of quantitative genetics. This proved a fertile approach and a series of papers resulted (see Evans, 1974*b*; Hamblin, 1977; Galwey, 1985). *Phaseolus* was a convenient test organism for work on biometrical genetics (Evans, 1970; Cheah, 1973; Davis, 1976; Hamblin & Evans, 1976; Davis & Evans, 1977; Hamblin & Morton, 1977), on interspecific hybridisation (Smartt, 1970; Miranda, 1974; Evans, 1980), plant competition (Hamblin, 1975, 1977), plant 'architecture' (Evans, 1974*a*; Evans, Cheah & Davis, 1975; Davis & Evans, 1977) and relationships between protein and yield (Gridley & Evans, 1979). In addition some material which was agronomically promising was obtained from the diallel crosses and this was progressed by selfing and intercrossing (Polignano, 1982). The main selection criteria were early maturity and pod height. Yield potential was considered to be of secondary importance and disease resistance to be unimportant until the navy bean crop was established in the UK (Galwey, 1985). In 1985 material from the Cambridge breeding programme was trialled by the PGRO. It was reported as substantially earlier than the standard (Michigan) control varieties (Anon., 1985).

At NVRS Austin & Maclean (1972) screened 305 of the Cambridge lines for cold tolerance, defined as an above-average relative growth rate at low (12·5 °C) temperatures. A total of 46 'good' and 11 'poor' genotypes were selected for further studies. A succession of field trials and experiments in controlled environment cabinets followed at NVRS, and later at Bangor and Dundee. These showed that although the procedure used by Austin & Maclean (1972) does not unfailingly identify lines with high rates of assimilation at low temperatures (it also includes lines with high rates of transfer of reserves from cotyledons to seedling axis), Austin & Maclean's 'good' genotypes included a number which are more cold tolerant than the Michigan navy bean Seafarer; (Hardwick & Andrews, 1980*b*; Thomas & Sprent, 1984*a*, *b*; Guye *et al.*, 1987). The NVRS breeding programme used some of these cold tolerant selections as parents together with others which had been shown to carry either race non-specific resistance to halo blight, multiple resistance to bean common mosaic virus, or resistance to the lambda race of anthracnose. The interim results of the NVRS breeding project are described by Conway *et al.* (1982). The first selections from the Cambridge and the NVRS programmes were entered for Plant Breeders Rights in 1978 and 1985 respectively (Table 2).

Table 2. *Varieties of dry bean admitted to the UK official list*

Name of variety	Dates of grant and termination of breeders' rights	Official maintainer	Parentage
(A) Navy beans on national list but not bred in the UK			
Purley King (=Seafarer)	2.10.74–30.11.81	J. K. King & Sons	Michelite x-ray mutant backcrossed Emerson 847, Robust, Crawford, Florida Belle, Mexican Tree (Andersen, 1983)
Revenge (=Seaway)	15.6.74–17.7.79	Charles Sharpe & Co. Ltd	Michelite x-ray mutant backcrossed Top Crop and others (Andersen, 1983)
(B) Navy beans bred in the UK			
Albion	19.1.87–	N. W. Galwey and NSDO	Seafarer × Turkish White
Anchor	1.3.78–16.3.82	C. L. A. Leakey	(Cuarantino × illegitimate determinate) F4 × (Kabanina × Mexicoll) F1 Kabanina was S74, a a selection from 64UN
Camphor (=Selection 9)	31.8.78–1.12.85	A. M. Evans and NSDO	Tenderwhite × Panameno
Drake (=37 PvH 9/3/8)	28.2.78–2.8.83	Charles Sharpe & & Co. Ltd	Early Warwick × Seafarer
Edmund (=PV 833131)	11.3.85–	NVRS	(Gratiot × (Seafarer × PI 150414) F2) F12
Longbow (=32 PvH 2/4/1)	18.4.79–17.4.83	Charles Sharpe & Co. Ltd	Ne Plus Ultra × Tendercrop
(C) Other (i.e. coloured) beans			
Camfleck (=Selection 7)	Rights never granted, application withdrawn	A. M. Evans	Panameno × Masterpiece
Horsehead (=Cross 10)	17.2.78–	C. L. A. Leakey & W. J. Unwin Ltd	Diacolnima × Cofinel Diacolnima from Columbia (Dr Camacho) Cofinel from Versailles (Dr Bannerot)
Sultan	21.4.86–		Selection from Swedish Brown

NSDO = National Seed Development Organization.
Source of information: *Plant Varieties and Seeds Gazette* 1978, 1983, 1985, 1986, and correspondence with the breeders.

DISCUSSION

A histogram of the papers reviewed in this paper, plotting numbers of papers/year versus year of publication (Fig. 1) shows a fairly well defined starting point in the late 1960's/early 1970's, (the prior work by Boyes in the 1930's at Cambridge apparently came to nothing), a burst of concerted activity, and a decline to almost zero in the mid-1980's. Thus the UK navy bean project is, at least so far as its publication record is concerned, a fairly neatly defined entity with beginning, middle, and (perhaps) end. It seems reasonable to suppose that a study of this project might reveal principles that would apply in other crop introduction projects.

The first point to be made is that the 'UK navy bean project' did not comprise one set of research activities subject to a single coordinating factor with one source of funding and a single overall master plan. Instead it comprised an assortment of research workers with varying degrees of involvement in the crop, at a number of different institutions, interacting both with each other and with other workers from around the world – more an 'invisible college' of workers than a coordinated team. This 'college' came together from different starting points. At Cambridge there was a prior interest in *Phaseolus* as a source of protein-rich grains for stock feed in the UK; at PGRO the prior interest was in the agronomy of green (culinary) beans; at NVRS there were bacteriological interests in halo blight of green beans, and physiological interest in *Phaseolus* as a laboratory subject for temperature response studies; at Wye there was a prior interest in alternative arable crops.

As the project progressed workers met on various occasions, materials and results were exchanged, and some engaged in collaborative work. But the papers from each site seem to have their own characteristic set of assumptions, concerns and procedures, suggesting that the initial diversity was maintained throughout the project. Citation analysis confirms that papers from the three main teams refer more to work of colleagues from the same site than to the literature in general. In a sample of 30 papers, 10 each from Cambridge, Wye and NVRS, there were 39 citations to papers by Cambridge authors of which 36 were in papers by other Cambridge authors. Similarly 22 of the 31 Wye citations and 62 of the 74 NVRS citations were 'self' references. Chi-squared for the deviation of these observations from the null expectation (each author cites papers from 'home' and 'away' impartially) are 195·6, 39·9 and 70·1 for Cambridge, Wye and NVRS respectively. The hypothesis of impartial citation is rejected (all three chi-squared have $P < 0{\cdot}001$, 1 D.F). Thus there were colleges within the college. This may not have been in the long term interests of the work. For in spite of the diversity all workers had the same strategic objective, i.e. to overcome the factors which limited the profitability of navy beans in the UK.

The most important limiting factor turned out to be the unsuitability of varieties bred in America to disease and weather conditions in the UK. Hence it became necessary

(1) to analyse the character X (X = full adaptation to UK conditions, or X = complete and durable resistance to halo blight, or to bean common mosaic virus),

(2) to find genetic sources of X, and finally

(3) to transfer the character X into a genetic background acceptable to the UK canning industry.

For X = halo blight resistance and X = bean common mosaic virus objectives, 1, 2 and 3 have been achieved; for X = adaptation they have not.

This is the central failure of the project and it comes perhaps as no surprise; although very superior sources of cold tolerance are known to be available in *Phaseolus* (see, e.g. White, Davis & Castillo, 1987), breeding for physiological characters has generally not been as successful as has breeding for disease resistance. Physiologists faced with this situation have often responded by redoubled efforts to analyse and understand the problem (tactical objective 1). Thus the Corporate Plan of the UK Agriculture and Food Research Council for the years 1987 – 1992 suggests, in discussing low temperature growth of plants 'an understanding of biochemical limitations to plant growth. . . might permit crops like soya bean to be adapted for production in the UK' (Anon., 1987*b*, p. 42). This might have been written 15 years ago by a partisan of the navy bean programme. For a substantial proportion of the total effort on navy beans at Cambridge, NVRS and elsewhere went into attempts to define 'adaptation to UK conditions', using either biochemical, physiological, agronomic or biometrical approaches; in other words, for X = cold tolerance, tactical objective (1) was pursued, while objectives (2) and (3) were relatively neglected. It is arguable that this was a mistake; that progress towards an adapted navy bean for the UK would have been hastened if the sophistication of approach had been reduced and the volume of material handled each year had been increased. The argument is that objective (1), a full understanding of cold tolerance, has not yet been achieved in any crop and that therefore it would have been better to bypass (1) and tackle (2) and (3) using a purely empirical approach. This is of course a judgement in hindsight; it may well be that some time in the future a full understanding of cold tolerance may be achieved, and that this may bring practical rewards. It also has to be acknowledged that the suggested redirection of effort from exploring new frontiers to working over existing material would have reduced the number of publishable papers that each worker could produce.

The pressure on scientists to do publishable work was only one of a number of extraneous factors acting on the project. For example the project started in response to 'market pull'; the prices of imported navy beans suddenly increased, UK farmers began experimenting with the crop, and the 'invisible college' of UK workers who were already interested and skilled in working with *Phaseolus* extended their interests to navy beans. Then market conditions changed and some trial crops failed. Farmer interest declined. But (Fig. 1) the 'technology push' factor was now mobilised and the project continued for some years, until other extraneous factors – failing funds, the redeployment of some and the death of other key workers – led to a decline in the project. Recently, yet another set of factors, unforeseen and unforeseeable at the start of the project, i.e. UK grain surpluses, the search for alternative crops, and a crop failure in 1986 in north America, have caused a sudden revival of commercial interest in navy beans. There are signs (Gent, 1985, 1986; Anon., 1987*a*) that the project may be restarted. Consideration of this history alongside the history of navy bean work in the USA (Andersen, Down & Whitford, 1960; Andersen, 1983) and of work on *Phaseolus* in France (see e.g. Bannerot, Derieux & Fouilloux, 1971) and in the Netherlands (see Drijfhout, 1978) suggests that crop adaptation and improvement by plant breeding is most effective when it is protected from extraneous factors which cause short term vagaries of personnel and of funding. Novel techniques of genetic manipulation may eventually enable shorter-term programmes with a much quicker turn round, but given existing technology it seems that progress in crop adaptation comes when a large scale long term programme is maintained for at least 20 years. Progress also requires that new material and techniques are incorporated as they come available and that ossified 'colleges within the college' do not develop.

To arrive at an overall summary we might consider the project in terms of costs and benefits. If we assume that government funds supported the equivalent of one scientist plus support staff at £50 000/annum for ten years at each of three sites, then the cost to the Exchequer of the UK navy bean project must have been of the order of £1·5 million. To this must be added a sum (difficult to estimate, but probably an order of magnitude smaller) for funding from other bodies. Then (still more difficult to quantify) there are the inputs which the project received of expertise, and of information and genetic material, much of it from overseas. These non-quantifiable inputs are probably more than matched by some corresponding outputs – of trained personnel (several generations of postgraduates at Cambridge and at Wye received their research training on the crop), of germplasm (which has been distributed widely), of utilities (e.g. computer programmes that were developed for curating breeders' collections (Andrews & Hardwick, 1982)), of expertise (work on virus and bacterial diseases on Phaseolus at NVRS led to collaborative projects in Africa and south America, which should benefit growers in those countries) and of information (see Fig. 1). Germplasm and information are enduring assets and should be credited to the capital account. But since there is as of now no UK navy bean crop, in narrow cash flow terms the project is in deficit to the order of perhaps £1·5 million. Set against the marginal cost of breeding one new cultivar of sugarbeet or wheat, which may exceed 4 million US dollars (Mastenbroek, 1988), this would seem to be a modest amount. Whether it is seen as an acceptable sum depends on how the boundaries are drawn. A more broadly based accounting procedure, making allowance for capital appreciation, might lead to the conclusion that the expenditure by the Exchequer and by other sources has resulted in the appreciation of a number of valuable assets, such as potential capital (germplasm) and intellectual capital (problems have been identified, understood and solutions have been found and published). Cynics might question whether information in the public domain should be counted a tradeable asset, while optimists might consider that this capital base may yet enable the navy bean to be established in the UK. But finally we have to recognise that in applied biology the possibilities of success and the risks of failure are inseparably intertwined. The history of the UK navy bean project only serves to underline this. In 1932 D. Boyes, in an unpublished report "Beans for Canning" submitted to the Ministry of Agriculture and Food, wrote "... there appears to be hope of eventually breeding a variety suitable for English climatic conditions". Fifty-six years later that hope remains to be realised. In applied biology we cannot quantify either the risks of failure, or our hopes of success.

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