*Expl Agric.* (1995), volume 31, pp. 361–370
*Printed in Great Britain*

# SELF-RESEEDING PASTURE BARLEY FOR MEDITERRANEAN DRYLANDS

*By* A. HADJICHRISTODOULOU

*Agricultural Research Institute, PO Box 2016, Nicosia, Cyprus*

*(Accepted 10 November 1994)*

## SUMMARY

Permanent pastures were successfully established with mixtures of bulks of crosses of *Hordeum vulgare* ssp. *vulgare* with ssp. *spontaneum* (given the name Mia Milia) and with mixtures of natural crosses involving H. *vulgare* ssp. *agriocrithon* (given the name Akhera). These crosses were made to exploit the brittle rachis gene of wild barley in order to develop self-reseeding pasture barley. No re-seeding of the pasture was necessary but a light cultivation to cover the seed in the first year of sowing improved plant establishment. No cultivation was necessary in the following years. Genotypes with a tough rachis were rapidly eliminated from the Milia pastures ($F_2$ bulks) because of their poor seed dispersal. Nitrogen and phosphorus fertilizer increased dry matter yield. Levels of seed dormancy in the wild barley were adequate to provide a safeguard against extreme dry weather conditions and other natural hazards. Forage quality was very high, with a crude protein content of 18% and digestible organic matter of 80% in harvested dry matter. Permanent barley pastures that exploit the brittle-rachis gene of indigenous genetic material have considerable potential for increasing the animal-carrying capacity of permanent pastures and marginal cropped lands.

*Cebada espontánea de pastos*

## RESUMEN

Se establecieron con éxito pastos permanentes con mezclas de cruces en grandes cantidades de *Hordeum vulgare* de la subespecie *vulgare* con la subespecie *spontaneum* (al que se ha llamado Mia Milia), y con mezclas de cruces naturales en los que toman parte el *H. vulgare* de la subespecie *agriocrithon* (al que se ha llamado Akhera). Se llevaron a cabo estos cruces para aprovechar el gen de eje quebradizo de la cebadilla con el fin de desarrollar cebada espontánea de pastos. No hizo falta el resembrado del pasto, pero un cultivo ligero para cubrir la semilla en el primer año de la siembra mejoró el asentamiento de la planta. Los años siguientes no hizo falta ningún tipo de cultivo. Los genotipos con un eje duro se eliminaron rápidamente de los pastos de Milia (segunda generación en grandes cantidades) debido a la pobre dispersión de la semilla. Los fertilizantes de nitrógeno y de fósforo aumentaron el rendimiento de la materia seca. Los niveles de semillas en letargo en la cebadilla eran adecuados para proporcionar una salvaguardia contra condiciones climáticas extremadamente secas y otros riesgos naturales. La calidad del forraje fue muy alta, con una proteína cruda del 18% y una materia orgánica digestible del 80% en la materia seca cosechada. Los pastos permanentes de cebada que explotan el gen de eje quebradizo del material genético autóctono tienen un potencial considerable para aumentar la capacidad de los pastos permanentes y de las tierras de pasto poco rentables para soportar carga animal.

## INTRODUCTION

Barley (*Hordeum vulgare* L.) is widely used as grain for malting purposes (in beer and other alcoholic beverages), for feeding livestock, and as human food (Srivastava, 1977; Parry and Parry, 1993). It is also used as green feed or made into hay or silage (Sprague, 1963). In some areas barley is grazed or used as a dual purpose crop, being grazed at the tillering stage and then harvested for grain (Hadjichristodoulou, 1983; Anderson, 1985).

There are no reports of barley being used as a pasture crop because *H. vulgare* ssp. *vulgare* cultivars lack the self-reseeding mechanisms which are necessary for the establishment of permanent pastures. However, Hadjichristodoulou (1988, 1992a) has reported preliminary data on the use of the brittle rachis gene of wild barley to develop permanent barley pastures.

Species suitable for establishing permanent pastures are available for European conditions, including the Mediterranean countries (Veronesi, 1991). These comprise grasses, mainly in the genera *Dactylis*, *Festuca* and *Lolium*, and legumes, mainly in the genera *Trifolium* and *Medicago*.

The lack of species suitable for sowing permanent pastures in West Asia and North Africa (WANA), or in Cyprus and other Mediterranean islands, has been pointed out by Hadjichristodoulou (1988). In spite of 50 years' work on pasture crops in Cyprus, there are no successful sown pastures there today and the same situation exists in the WANA region, where sown pastures with medics, clovers and Loliums have failed. The reasons are related to the limited amounts of annual precipitation and its distribution within the season, compared with European conditions. The total annual precipitation in most areas is only 150–350 mm, concentrated in six months, from November to May.

Barley is the most productive crop in the dry Mediterranean areas (Hadjichristodoulou, 1988) but, as already pointed out, the common cultivars lack the self-reseeding mechanism necessary to establish permanent pastures. A brittle rachis gene ensures the self-regeneration of wild barley, which is abundant in the WANA countries and the Mediterranean islands including Cyprus (Harlan, 1979; Hadjichristodoulou, 1992b).

Brittle rachis genes exist in *Hordeum vulgare* ssp. *spontaneum* and *agriocrithon*. Brittleness is controlled by one dominant gene or two to three complementary genes (Nilan, 1964). Several authors have shown that ssp. *agriocrithon* (six-rowed, with a brittle rachis) is the product of natural outcrosses of ssp. *spontaneum* with six-rowed ssp. *vulgare* cultivars (Zohary, 1959; Hadjichristodoulou, 1992b). *Hordeum vulgare* ssp. *agriocrithon* is more leafy than ssp. *spontaneum* because it has genes from ssp. *vulgare*.

The conditions under which the brittle rachis gene of wild barley could be used to develop pasture barley were investigated in the present studies.

## MATERIALS AND METHODS

The pasture barley material used in these studies originated from three populations: a mixture of spikes of over 5000 ssp. *spontaneum* wild barley plants; a mixture of spikes of 2400 plants of ssp. *agriocrithon*, given the name Akhera; and bulks of 117 crosses between leafy ssp. *vulgare* varieties and wild barley (ssp. *spontaneum* or ssp. *agriocrithon*), given the name Mia Milia. The wild barley plants were selected from the central, driest, part of Cyprus (west of Nicosia) (annual precipitation 280–300 mm). The ssp. *vulgare* parents represented the most promising material of the breeding programme, including commercial varieties.

Akhera and mixtures of ssp. *spontaneum* were multiplied for seed production at Athalassa, Nicosia and harvested at physiological maturity, just before seed shattering. The sun-dried plants were threshed by an experimental combine. For Mia Milia, the $F_2$ of the crosses was grown at Athalassa. The plants with a brittle rachis shed their seed into the soil. Then the plants with a tough rachis and the remaining roughage were grazed by sheep in the summer. This process still continues, but very few tough rachis genotypes remained in the population after the first three or four years.

Since no information was available on the use of the genus *Hordeum* as a self-reseeding pasture, preliminary studies were conducted to collect essential information on how to sow and manage permanent pastures.

*Germination tests*

The number of days from sowing to seedling emergence and the final percentage plant establishment of pasture barley were investigated in pot and field experiments. One hundred seeds of *H. vulgare* Athenais, ssp. *spontaneum*, Akhera and Mia Milia, were sown on aluminium plates filled with sand, covered and kept at 20°C and about 90% relative humidity. The numbers of normal seedlings emerging from the 100 seeds per plate were counted daily, until no more seedlings emerged. This experiment was replicated five times. The test was repeated in the field in one trial in 1992 with two sowing dates, 22 January and 30 November in 1993, and using two 5-m long rows, spaced 30 cm apart, with 100 seeds per plot. The four populations were sown in a randomized complete block design with four replications. Emerging seedlings were again counted daily.

*Sowing method*

The method of sowing plays a decisive role in the year of pasture establishment. Two methods were compared: broadcasting the seed on the soil surface, without any interference; and covering the broadcast seed using hand rakes to simulate light cultivation. These two methods were applied at five sites using two populations, Mia Milia and a mixture of seed of ssp. *spontaneum*, at two nitrogen fertilizer levels, 40 and 60 kg N $ha^{-1}$. The seed rate was 83 kg $ha^{-1}$, but because of differences in 1000-grain weight, 174 seeds $m^{-2}$ were sown for Mia Milia and 203 $m^{-2}$ for ssp. *spontaneum*. The number of plants established per plot was recorded. There were no replications in the sites, which were used as replications in the analysis of variance. The plot size was 12 $m^2$.

In situ *test of dormancy*

*Hordeum vulgare* ssp. *spontaneum* grows in dense natural undisturbed populations in a National Park at Athalassa, near Nicosia. Four 3.5 $m^2$ plots located within 1 km of each other were marked in spring 1989 and the seed was allowed to drop as usual onto the soil. The seeds germinated the following November, soon after the first autumn rains, and grew until the flowering stage in April 1990. Plants established within the marked area, and up to 1 m around the plot, were then cut before seed formation. The plots were covered with canvas, to ensure that seeds from neighbouring plants could not drop on them. In contrast to other material such as plastic, canvas protects the soil from the high air temperatures of 35–40°C which occur during summer. The canvas was removed in November 1990, after the first autumn rainfall. Plants established in the plot were therefore produced from seeds which had been dormant for at least one year. All the plants were cut and removed at the flowering stage and the plot was covered by canvas again. The same procedure was followed until spring 1994, when the last count was taken. All plants in the plot in spring 1994 originated from seeds which had been dormant for at least four years.

*Permanent pastures*

The first permanent pasture was sown in 0.1 ha of shallow land at Athalassa in 1985, using a mixture of $F_2$ bulks of 42 crosses of ssp. *vulgare* cultivars with ssp. *spontaneum*. The seed was broadcast and covered by a light cultivation. Another area of 0.5 ha was sown in 1986 with a mixture of bulks of 75 new crosses. The mixture of the 117 crosses was named Mia Milia. An additional area of 1 ha was sown in 1989 with a mixture of 2400 genotypes of ssp. *agriocrithon* (six-rowed, brittle rachis), named Akhera. Since then, these pastures have been grazed one to three times during January-February at the tillering stage and then as dry pastures after seed shattering. No cultivation was done, except in the year of establishment. Each year, 25 kg N and $P_2O_5$ ha$^{-1}$ were applied in November, and during grazing an additional 30 kg N ha$^{-1}$ was applied as a top dressing. The precipitation in 1990/91 was only 133 mm, so there was no grazing, and no top dressing with nitrogen fertilizer was necessary. Annual precipitation between 1989/90 and 1993/94 ranged from 133 to 316 mm.

*Yield of pasture barley*

Two populations of pasture barley, namely a mixture of ssp. *spontaneum* genotypes and Mia Milia were compared with natural vegetation. Earlier studies had shown that 30 kg N and 20 kg $P_2O_5$ ha$^{-1}$ applied to natural pastures on uncropped land increased forage dry matter by 2.5 times (ARI, 1967). These two populations were therefore tested at two nitrogen fertilizer rates, 40 and 60 kg N ha$^{-1}$. A uniform application of 50 kg $P_2O_5$ ha$^{-1}$ was applied at sowing in the year of pasture establishment and soon after the first autumn rains in the following years. The six treatments, natural vegetation and the two pasture barley populations at two nitrogen levels, were randomized in 24 m$^2$ plots, and sown on seven natural pasture sites. Sites and years were treated as replications. Two of the sites were lost because of outside interference after the first year, therefore no yield data were recorded from those sites.

Dry matter yield was recorded at the tillering stage (grazing time) in January-February and dry pasture yield in summer after maturity. Crude protein content (N% × 6.25) and *in vitro* digestibility of the organic matter in the herbage dry matter were also recorded.

## RESULTS

### *Seed germination and plant establishment*

In the laboratory tests, seeds of ssp. *spontaneum* took longer to start germinating and to reach maximum germination percentage than those of cv. Athenais, germination of the crosses (Mia Milia) and of ssp. *agriocrithon* (Akhera) being intermediate (Fig. 1). The final number of plants of cv. Athenais was higher than that of the wild barley populations. Establishment under field conditions showed a similar pattern (Table 1).

In the case of bulks of crosses (Mia Milia) 36% of the covered seeds in the first year produced plants compared with 15% of the uncovered seed, while in the case of ssp. *spontaneum*, 24% and 15%, respectively, of the seeds produced plants. Levels of nitrogen fertilizer had no significant effect on stand establishment.

As no seeds were produced in the plots covered with canvas in spring 1990 for the seed dormancy test, the plants produced in winter 1991 originated from the seeds of spring 1989 or earlier (that is, from seeds that had been dormant for one year or more).

The number of plants established varied between 10 and 60 m$^{-2}$ (a mean of 43 plants), apparently expressing the differences in the plant density of the plot at the

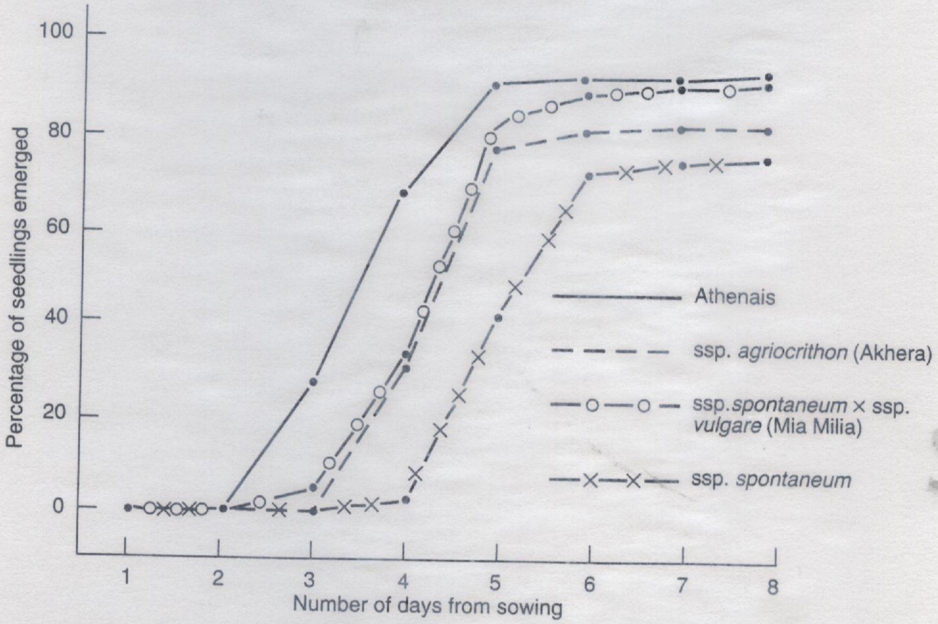


Fig. 1. Daily emergence of seedlings (% of total seeds) of cv. Athenais and three pasture populations.

time of initiation of the test. The mean germination in the next three years was 10, 5 and 1.7 plants $m^{-2}$ (Fig. 2).

*Permanent pastures*

The $F_2$ bulk populations, sown in pasture lands, segregated into tough and brittle rachis genotypes. After five to eight years of self-regeneration, tough rachis

Table 1. *Stand establishment (%) of wild barley and wild barley crosses under field conditions*

| Population | Date of sowing | | |
|---|---|---|---|
| | 4/12/92 | 22/1/93 | 30/11/93 |
| Athenais | 60 | 93 | 96 |
| Ssp. *agriocrithon* (Akhera) | 51 | 81 | 92 |
| Ssp. *spontaneum* × ssp. *vulgare* (Mia Milia) | 50 | 87 | 92 |
| Ssp. *spontaneum* | 45 | 86 | 89 |
| SE | 1.7 | 3.0 | 1.1 |

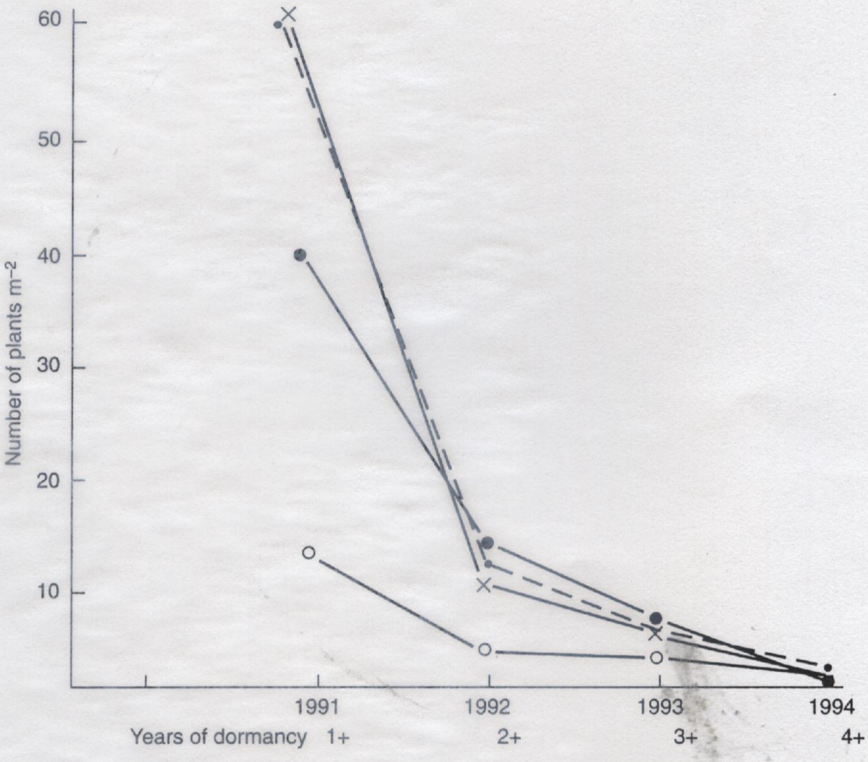


Fig. 2. Number of plants of ssp. *spontaneum* counted in four sites in spring 1991–1994.

genotypes were practically eliminated, because their spikes were selectively eaten by animals and their seeds by birds and ants.

All the pastures were grazed between one and three times at the tillering stage according to precipitation, and again in May and June as dry pasture. Regeneration was excellent in all seasons, giving very dense plant populations, but grazing at the tillering stage was not practised in 1990/91 to allow seed production, as the precipitation was only 133 mm.

The emergence date depended on the date of the first effective rains, that is, rains sufficient to keep the soil surface wet for three or four days. In some years early emergence at the beginning of November was followed by long dry periods of 30–40 days so that the above-ground vegetation died. However, the pastures soon recovered after rain, turning from yellow to green in four or five days. Emergence was later in bare spots of the pasture, where the stubble had been completely removed from the ground by sheep.

Seed production, following controlled grazing, was sufficient to allow the establishment of a very thick stand, without any cultivation to cover the seed. In some years, strips 1.5 m wide were harvested by a mower at the time of physiological seed maturity (before seed-shattering) in order to obtain seed for the establishment of new pastures. Stand establishment in these strips was excellent, apparently resulting from seeds produced on neighbouring plants or from previously dormant seeds.

The dry matter yield of samples at the grazing stage (end of February, 30–70 cm plant height) was 2.9 t $ha^{-1}$ for Mia Milia and 2.3 t $ha^{-1}$ for Akhera (mean of eight samples in the 1993/94 season). The crude protein content of forage dry matter was 20–23% at this stage. The total dry matter produced from grazing both green and dry pasture was 8.7 t $ha^{-1}$ for Mia Milia and 6.5 t $ha^{-1}$ for Akhera. These yields were comparable to those from barley in neighbouring fields.

Unfertilized unsown pastures around the trial sites produced negligible amounts of dry matter, though natural vegetation fertilized with 60 kg N $ha^{-1}$ produced significantly more dry matter than that receiving only 30 kg N $ha^{-1}$ (Table 2).

The higher nitrogen application rate also increased dry matter yield in the pastures sown with Mia Milia or with the mixture of ssp. *spontaneum*. But the dry matter yields of the ssp. *spontaneum* mixture when grazed green or as dry pasture tended to be lower.

There was a wide variation in the proportion of weeds in the total dry matter produced at the grazing stage in the sown pastures, reflecting differences in the stand of sown pastures; plots having thin stands were full of weeds. The weed content of the dry pasture, after crop maturity, ranged from 6 to 54% (mean 36%).

There were no significant differences between pastures in the percentage of protein or the percentage of digestible organic matter in herbage dry matter (DOMD) at the grazing stage (Table 2). The crude protein content of the dry pasture was around 5% with no significant differences among treatments.

## DISCUSSION

Wild barley, adapted to Mediterranean drylands, has potential as a crop for establishing self-reseeding pastures because of its brittle-rachis gene. Hadjichristodoulou (1993) showed that the brittle rachis gene of wild barley can be easily manipulated by breeding, in order to develop productive, self-reseeding permanent pastures. The seed-dispersal mechanisms of the brittle rachis gene of ssp. *spontaneum* and ssp. *agriocrithon* in natural habitats have provided the necessary protection for their survival over thousands of years. The present study has also shown that the self-regenerative capacity of pasture barley, including crosses of ssp. *vulgare* with wild barley, is sufficient to maintain a permanent pasture provided that grazing by sheep is controlled. Selection pressure from biotic factors (sheep, birds and insects) eliminated most of the tough rachis genes from the bulk crosses during the first three or four years of the pasture. Through this process the pasture population tends to improve continuously, by the elimination of genotypes with poor seed dispersal systems.

Seed dormancy is also important in determining the survival of pasture species. El-Moneim and Cocks (1986) showed that 87% of the medic seeds in a wheat–medic rotation had been dormant for at least one year. Wild barley shows less dormancy but the survival of the barley pastures is safeguarded because adequate numbers of dormant seeds survive in the soil for one year, and a few survive for four or more years (Fig. 1). Pasture barley has the advantage of producing seeds every year, compared with every other year in the medic–wheat rotation.

Table 2. *Dry matter yield ($t\ ha^{-1}$), percentage crude protein and percentage digestible organic matter in dry matter of herbage (DOMD) of barley pastures derived from natural vegetation, from bulks of crosses of ssp.* vulgare *with ssp.* spontaneum *(Mia Milia) and ssp.* spontaneum, *receiving 40 and 60 kg nitrogen $ha^{-1}$*

| | Dry matter yield ($t\ ha^{-1}$) | | At grazing (tillering stage) | |
|---|---|---|---|---|
| | At grazing stage | Dry pasture (maturity) | Crude protein (%) | DOMD (%) |
| Natural vegetation | | | | |
| 40 kg N $ha^{-1}$ | 0.21 | 0.93 | 14.8 | 62.7 |
| 60 kg N $ha^{-1}$ | 0.54 | 0.95 | 17.1 | 73.0 |
| Mia Milia | | | | |
| 40 kg N $ha^{-1}$ | 0.54 | 1.05 | 18.1 | 75.8 |
| 60 kg N $ha^{-1}$ | 1.02 | 1.56 | 18.8 | 80.7 |
| Ssp *spontaneum* | | | | |
| 40 kg N $ha^{-1}$ | 0.64 | 1.16 | 17.1 | 81.8 |
| 60 kg N $ha^{-1}$ | 0.87 | 1.29 | 18.8 | 79.2 |
| SE | 0.092 | 0.097 | 1.81 | 1.82 |

On the basis of the results and observations from the present studies, the following factors must be considered in establishing pastures with self-regenerating barley. In the first year of establishing the pasture it is necessary to use an adequate seed rate (80–100 kg $ha^{-1}$), followed by a light cultivation, to produce a good stand. Grazing must be controlled, according to the amounts of rainfall and its distribution, to allow for seed production after the middle of March. Nitrogen and phosphorus fertilizer rates must be adjusted according to the amount of dry matter removed by grazing animals. Selective herbicides must be applied to control weeds, if the need arises. Stubble grazing must be controlled to leave a thin layer of dry leaves on the soil. Seed for the establishment of new pastures can be produced from special multiplication areas or from strips harvested in pastures where machinery can operate. Harvesting for seed must be done with a mower at physiological maturity and the threshing of the sun-dried plants with a grain combine.

*Acknowledgements.* I am grateful to M. Mouzouris, L. Daniel, G. Alexandrou and Chr. Theodorides for valuable assistance throughout these studies and to the staff of the Central Chemistry Laboratory of the Institute for the protein and digestibility analyses.

## REFERENCES

Anderson, W. K. (1985). Production of green feed and grain from grazed barley in Northern Syria. *Field Crops Research* 10:57–75.

ARI (1967). Range improvement trial. *Annual Report for 1966*, 9–10. Nicosia: Agricultural Research Institute.

El-Moneim, A. M. Abd & Cocks P. S. (1986). Adaptation of *Medicago rigidula* to a cereal–pasture rotation in north-west Syria. *Journal of Agricultural Science*, Cambridge 107:179–186.

Hadjichristodoulou, A. (1983). *Dual Purpose Barley. Technical Bulletin No. 46*. Nicosia: Agricultural Research Institute.

Hadjichristodoulou, A. (1988). The use of *Hordeum spontaneum* to breed for grain and self-regenerating pasture. In *Cereal Breeding Related to Integrated Cereal Production*, 195–199 (Eds M. L. Jorna and L. A. J. Sloomaker). Wageningen, The Netherlands: Pudoc.

Hadjichristodoulou, A. (1992a). A new domestication of the "wild" brittle rachis gene of barley (*Hordeum vulgare* L.). *FAO/IBPGR Plant Genetic Resources Newsletter* 90:46

Hadjichristodoulou, A. (1992b). Collecting, evaluation and utilization of *Hordeum vulgare* subsp. *agriocrithon* in Cyprus. *FAO/IBPGR Plant Genetic Resources Newsletter* 90, 15–18.

Hadjichristodoulou, A. (1993) The use of wild barley in crosses for grain production under dryland conditions. *Euphytica* 69:211–218.

Harlan, J. R. (1979). On the origin of barley. In *Barley. Agricultural Handbook No 338*, 10–36 (Ed. by USDA). Washington, DC:USDA.

Nilan, R. A. (1964). *The Cytology and Genetics of Barley. Monographic Supplement No. 3*. Washington: State University.

Parry, M. L. & Parry, C. J. (1993). Agricultural geography of barley. In *The Agrometeorology of Rainfed Barley-based Farming Systems*, 15–31 (Eds M. Jones, Gustave Mathys and D. Rijks). Syria: International Center for Agricultural Research in Dry Areas (ICARDA).

Sprague, A. M. (1963). Cereals as forage. In *Forages*, 337–345 (Eds H. D. Hughes, M. E. Heath and D. S. Metcalfe). Ames, Iowa: State University.

Srivastava, J. P. (1977). Barley production, utilization and research in the Afro-Asian region. In *Barley, Proceedings of the Fourth Regional Winter Cereal Workshop, Volume II*, 242–259 (Eds S. Barghouti, E. E. Saari,

J. P. Srivastava and G. Chancellor). Aleppo, Syria: International Center for Agricultural Research in Dry Areas (ICARDA).

Veronesi, F. (1991). Achievements in fodder crop breeding in Mediterranean Europe. In *Fodder Crops Breeding: Achievements, Novel Strategies and Biotechnology, Proceedings of the 16th Meeting of the Fodder Crops Section of Eucarpia, Wageningen, 18–22 November 1990*, 25–30 (Eds A.P.M. den Nijs and A. Elgersma). Wageningen: Pudoc.

Zohary, D. (1959). Is *Hordeum agriocrithon* the ancestor of six-rowed cultivated barley? *Evolution* 13:279–280.

*Expl Agric.* (1995), volume 31, pp. 371–381
*Printed in Great Britain*

# THE USE OF MANURE ON SMALLHOLDERS' FARMS IN SEMI-ARID EASTERN KENYA

*By* M. E. PROBERT†, J. R. OKALEBO‡ *and* R. K. JONES†

*KARI/ACIAR/CSIRO Dryland Project, Nairobi, Kenya*

*(Accepted* 23 *November* 1993*)*

## SUMMARY

The manure that is returned to croplands each year is an important resource in the subsistence farming systems of eastern Kenya. Measurements on several farms have shown that the manure being used is of very poor quality. Analyses of soil samples from beneath the *bomas* (small enclosures) where animals are kept indicate that substantial losses of nutrients occur through leaching; ammonia volatilization and denitrification may also be involved. Current practice is to apply the manure at rates that appear to make poor use of this scarce resource. The findings are discussed in terms of what changes to the system may be feasible to reduce losses of nutrients, and to improve the quality of the manure and the effectiveness of its use.

*El estiércol en explotaciones agrícolas minifundistas*

## RESUMEN

El estiércol que los animales depositan en las tierras de cultivo cada año es un recurso importante en los sistemas agrícolas de subsistencia de Kenia oriental. Las mediciones en varias explotaciones agrícolas han mostrado que el estiércol utilizado es de muy baja calidad. Los análisis de las muestras de tierra cavada en las *bomas* (pequeños cercados) que soportan animales indican que se da una pérdida importante de nutrientes mediante la filtración del agua; puede que la volatilización del amoniaco y la desnitrificación también influyan. La práctica actual es aplicar el estiércol en proporciones que parecen utilizar ineficazmente este recurso tan escaso. Las conclusiones se discuten concentrándonos en qué cambios al sistema pueden ser viables para reducir la pérdida de nutrientes y para mejorar también la calidad del estiércol y las efectividad de su uso.

## INTRODUCTION

Cropping without replacement of the nutrients removed in the crops must ultimately result in soil impoverishment and poor crop yields. This is already a problem for many subsistence farmers in the semi-arid areas of eastern Kenya, and yields of maize are low even in seasons that receive above average rainfall. Nutrient deficiencies are widespread; the shortage of nitrogen is obvious from the appearance of the crops in the field but, in addition, soil phosphorus status is very variable with low values of extractable phosphorus in many of the cropland soils (Okalebo *et al.*, 1992). In spite of the severity of the problem, the risk of crop

Present addresses: †CSIRO Division of Tropical Crops and Pastures, 306 Carmody Road, St Lucia, Queensland 4067, Australia; ‡Kenya Agricultural Research Institute, National Agricultural Research Centre (Muguga), PO Box 30148, Nairobi, Kenya.