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KAUN- JA TERAVILJADE SEGUKÜLVIDE KASVATAMISE TEOREETILISI JA PRAKTILISI ASPEKTE

THEORETICAL AND PRACTICAL ASPECTS OF GROWING LEGUME–CEREAL MIXES

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Käesolev väitekiri põhineb järgnevatel artiklitel, mis on väitekirja tekstis viidatud vastavate rooma numbritega. Allnimetatud ajakirjade toimetused on andnud loa artiklite publitseerimiseks väitekirjas.

I Lauk, R., Lauk, E. 2008. Pea–oat intercrops are superior to pea–wheat and pea–barley intercrops. *Acta Agriculturae Scandinavica – Section B, Soil and Plant Science* Volume 58, No. 2, 139–144.

II Lauk, R., Lauk, E., Lauringson, E., Talgre L., 2007. Vetch–wheat crops are superior to vetch–oat crops in terms of protein yield. *Acta Agriculturae Scandinavica – Section B, Soil and Plant Science* Volume 57, No. 2/May, 116–121.

III Lauk, R., Lauk, E. 2006. Yields in vetch–wheat mixed crops and sole crops of wheat. *Agronomy Research*, 4 (1), 37–44.

IV Lauk, E., **Lauk, R.,** 2005. The yields of legume–cereal mixes in years with high–precipitation vegetation periods. *Latvian Journal of Agronomy* Nr. 8., 281–285.

V Lauk, E., **Lauk, R.**, 2004. On the effect of nitrogen fertilizer on mixed seedings of common vetch (*Vicia sativa* L.) and wheat (*Triticum aestivum* L.). *VAGOS, Research papers* 64 (17), 38–43.

1. SISSEJUHATUS

Praeguses põllumajanduslikus tootmises on päevakorras energiakultuuride kasvatamine bioenergia saamiseks. Samas ei tohi nende kultuuride kasvatamise propageerimise käigus seada ohtu meie toidulauda ja teatud kindlate kultuuride kasvatamisele keskendudes ka bioloogilist mitmekesisust ökosüsteemis. Ökoloogiline printsiip ütleb, et looduslikult keerukam ja mitmekesisem agroökosüsteem on stabiilsem ning isereguleeruvam. Teravilja kasvatatakse praegu maailmas ülekaalukalt puhaskülvis. Puhaskülvis kasvatamise eeliseks on külvamise, koristamise ja teiste tööoperatsioonide lihtsus, mis on kergesti mehhaniseeritavad ning tulemuseks on kvaliteetne toodang. Kuid siin on omad ohud. Keskendudes põhiliselt puhaskülvis kultuuride kasvatamisele tuleb arvestada mitmete ebasoodsate väljunditega, kuna selline viljelemine eeldab suuremas ulatuses pestitsiidide, väetiste, kasvuregulaatorite jm. sisendite kasutamist (Altieri, 1999; Wolfe, 1999; Hauggaard–Nielsen *et al*., 2001; Jensen *et al*., 2005). Sellega kaasneb reostussurve suurenemine keskkonnale. Bioloogilist mitmekesisust on võimalik suurendada, võttes külvikorda võimalikult palju kultuure. Põllukultuuride kasvatamist saab mitmekesistada, kasutades erinevaid sorte, kuid ka sortide– ja liikidevahelisi segukülve. Viimastest on tuntumad kaunvilja–teravilja segukülvid.

Nimetatud segukülvide laialdasemat levikut on seni piiranud kaunviljade raskendatud seemnekasvatus, külvide umbrohtumine, taimiku lamandumine ja viki (*Vicia sativa* L.) puhul ka seemnete ebaühtlane valmimine (Lampkin, 1990; Reimets, 1993; Dimitrova, 1997). Kaunviljade kasvatamine koos tugikultuuridega vähendaks nende lamandumist (Anil, *et al*., 1998). Vihmastel aastatel on herne (*Pisum sativum* L.) segukülvides kasvatamine olnud ainsaks võimaluseks kvaliteetse herneseemne saamiseks (Kalev, Hindoalla, 1985). Tugikultuuridest on osutunud sobivamateks nisu (*Triticum aestivum* L.), oder (*Hordeum distichon* L.), kaer (*Avena sativa* L.) ja suvitritikale (*Triticisecale* Wittmack) (Caballero, Goicoechea, 1986; Thompson *et al*., 1992; Lithourgidis *et al*., 2006), kusjuures kaer on nendest kõige levinum, kuigi tootjad eelistaksid mõnikord hoopis nisu või otra (Common…, 1997). Katsed on näidanud, et segukülvides lühendavad tugikultuurid kaunviljade kasvuaega, soodustavad seemnete ühtlasemat valmimist ning vähendavad lamandumist (Rosentals, 1970; Leis, Lauk, 1996). Valides segukomponendid, mis valmivad enam–vähem üheaegselt, on saagi koristamine kombainiga täiesti võimalik ja selle koristusjärgne töötlemine palju lihtsam. Segavilja kasutatakse eelkõige loomasöödaks aga

ka kaunvilja seemne paljunduseks, sorteerides segukülvide saagi hilisema koristusjärgse töötlemise käigus.

Kaunviljade–teraviljade kooskasvatamisel on tähtis see, et kaunviljadel on hästi arenenud sammasjuurestik, teraviljadel aga narmasjuurestik, mistõttu on konkurents väiksem mullast omastatavatele toitainetele. Kaunviljad rikastavad mulda lämmastikuühenditega ning tänu sellele paranevad nii tugi– kui ka järgneva kultuuri lämmastiktoitumise tingimused (Jensen, 1996b; Papastylianou, 1990; 2004). Seega sobiksid segaviljad ökoloogilise talupidamisviisi juurde, kuna nad asendaks teatud ulatuses mineraalseid lämmastikväetisi. Segaviljapõllult on leitud ka vähem haigusi ja kahjureid, võrreldes eri liikide puhaskülvidega (Reimets, 1993; Altieri, 1999; Jensen *et al.,* 2005). Viki–teraviljade segukülvides ei ole vajalik kasutada insektitsiide, sest hernemähkuri kahjustust vikil praktiliselt ei esine. Küll aga on leitud, et suvivikk on tundlik kaunviljadele mõeldud herbitsiidide suhtes (Lauk *et al*., 2000) ning seetõttu ei saa viki–teraviljade segukülve herbitsiididega pritsida. Samas on kaunviljade–teraviljade segukülvid umbrohtude suhtes konkurentsivõimelisemad (Mohler, Liebman, 1987; Liebman, Dyck, 1993; Rauber *et al*., 2001; Talgre *et al*., 2005; Hauggaard–Nielsen *et al*., 2006) ja suruvad umbrohte suuremal määral alla kui kaunviljade puhaskülvid (Hauggaard–Nielsen *et al*., 2001). Seejuures aitas umbrohtumust rohkem alla suruda kaunviljade külvisenormi suurendamine segukülvis (Talgre *et al*., 2005). Kaunviljad (aga ka segaviljad) on osutunud teraviljarohkes külvikorras fütosanitaarseks kultuuriks, tänu millele vähenes järgnevatel aastatel külvatud kultuuride haigestumine mitmetesse taimehaigustesse (Jones, Arous, 1999; Enneking, 2001). Kaunviljade–teraviljade segudest on saadud ka kõrgemaid seemne– ja proteiinisaake kui teraviljade puhaskülvidest (Jensen, 1996a; Hauggaard–Nielsen *et al*., 2001). Need olid eriti märgatavad tingimustes, kus segavili järgnes teraviljale ja mineraalseid lämmastikväetisi ei kasutatud (Lauk, Jaama, 1995; Lauk, Leis, 1997). Loomatoiduna peetakse segaviljapõhku puhaskultuurina kasvatatud teraviljaliikide põhust paremaks, kuna kaunviljad suurendavad põhu proteiini– ja kaltsiumisisaldust, mõnevõrra paraneb ka seeduvus (Tamm *et al*., 1999). Loomad eelistavad segaviljapõhku teraviljapõhule.

Eestis on segaviljade külvipinnad aastate lõikes väga suurel määral varieerunud. Näiteks külvati 1939. aastal segavilja 126 689 hektarile. Sõjaeelses Eestis oligi segavili põhiline proteiinirikka jõusööda allikas, mis aitas ületada proteiinidefitsiiti, mis võis kaasneda ühekülgse teraviljakasvatusega (Kaarli *et al*., 1995; Karelson, 1997). Segaviljakasvatuse kogupind oli kõrge ka järgneval, 1940. aastal, 116 100 hektarit (Kaarli *et al*., 1995). Sõjajärgne majanduspoliitika, eriti aga üleminek kombainidega viljakoristusele, põhjustas herne ja segavilja kasvatamise tunduva vähenemise (Kaarli *et al*., 1995). Nii oli segukülvide kasvupind 1965. aastaks vähenenud ligikaudu kümnekordselt ning jäi pea paarikümneks aastaks vahemikku 10 000–20 000 ha. Alla 10 000 ha langesid segavilja külvipinnad aastatel 1989–1995. Uus langus algas 2001. aastast ning 2006. aastaks oli segavilja kasvupind langenud madalaimale tasemele, vaid 4900 ha (Põllukultuuride…, 2007).

Kaunvilja–teravilja segukülvide alaseid uuringuid viiakse praegu läbi mitmel pool maailmas. Mõnes Euroopas läbiviidavates uuringustes määratakse näiteks kahjurite arvukuse taset ning saagi lämmastiku– ja väävlisisaldust (Hansen, Lorentsen, 2005; Kasyanova, 2006). Lisaks kaunvilja–teravilja segudele uuritakse ka teraviljade sortidevaheliste segude kasutamise võimalusi eesmärgiga muuta külvid haiguskindlamaks (Wolfe, 1999; Munk, 1999; Lannou, Pope, 1999). Uurimistöid tehakse ka teraviljade liikidevaheliste segukülvide alal (nt. oder+kaer, oder+suvinisu jm.), kusjuures sellised segukülvid on osutunud saagikamateks kui vastavate liikide puhaskülvid (Nadziak, Gacek, 2000). Viki ja teraviljade kooskasvatamise võimalusi on uuritud nii Vahemere– kui ka Skandinaaviamaades, kusjuures paremaid tulemusi on saadud nende segude kasutamisel haljasmassiks ja siloks (Dhima *et al*., 2007; Lithourgidis *et al*., 2006; Kuusela *et al*., 2004). Indias saadud tulemuste põhjal on jõutud järeldusele, et segaviljad aitavad vähendada saagi ikalduse riski võrreldes puhaskülvidega (Chatterjee, Mandal, 1992).

Viimase kümnekonna aasta jooksul on Eesti Maaülikooli taimekasvatuse ja rohumaaviljeluse osakonnas viidud läbi rida uuringuid viki ja herne kasvatamisest segu– ja puhaskülvides (Lauk, Leis, 1998; Lauk, *et al*., 1999a.). Saadud tulemustest lähtudes valitigi käesolevas uurimuses segaviljade komponentideks vikk ja hernes. Valikul lähtuti ka sellest, et nii varasematest katsetest kui ka näiteks Lukina poolt (1986) saadud tulemustest võis järeldada, et nii vikk kui hernes on saagikad, pika perioodi jooksul söödana kasutatavad ja väärtusliku keemilise koostisega. Häid tulemusi on saadud ka nende kultuuride kasvatamisel koos kõrrelistega nii haljassöödaks, haljasväetiseks, seemneks, siloks ja ka heinaks (Caballero *et al*., 1998; Jones, Arous, 1999; Tekeli, Ates, 2003). Mitme autori andmeil on vikijahu hea kontsentreeritud valgurikas sööt paljudele koduloomadele (veistele, lammastele), kuid tema kasutamine inimtoiduks on küsitav,

kuna on täheldatud toksilisust rottidele ja lindudele (Roy *et al*., 1996; Chowdhury *et al*., 2001; Enneking, 2001).

Kuivõrd segukülvide all mõistetakse segusid, mille kooskasvatamiseks on valitud enam kui üks kultuur (Willey, 1979), seisab põllumajandusteadlastel ees ülesanne välja selgitada, missuguseid kultuure eelistada kooskasvatamiseks erinevates kliimatingimustes, missugune on liikidevaheline vastastikune mõju segukülvides ja kuidas see mõjutab taimede vegetatiivset kasvu ning seemnesaaki. Nendest ülesannetest lähtuti ka antud uurimistöö teema püstitamisel. Antud töö lisaväärtuseks võib kujuneda see, et läbi tulemuste propageerimise julgustame Eesti põllumajandustootjaid kasvatama segavilja. Väljavalitud kaunviljadele võeti tugikultuurideks meil peamiselt kasvatatavad suviteraviljad nisu, kaer ja oder, kuna need teraviljad on traditsioonilisteks tugikultuurideks kaunviljadele Eesti tingimustes.

2. KIRJANDUSE ÜLEVAADE

2.1. OLULISEMAD SEGUKÜLVIDE SAAKI MÕJUTAVAD TEGURID

2.1.1. Liikidevahelised suhted segukülvis

Põllumajandus on tihedalt seotud keskkonnaga olles osa ökosüsteemist. Agroökoloogia keskendubki ökoloogilistele protsessidele põllul (toitainete ringlus, vastastikune mõju saagi kujunemisele jm.), mille raames uuritakse taimede arengut, taimse produktsiooni formeerumist, biomassi kujunemise kulgu ajas ja neid protsesse mõjutavad tegureid. Tundes nende protsesside ja suhete kulgu võime agrosüsteemi juhtida nii, et saame suuremat toodangut väiksemate negatiivsete keskkonna ja sotsiaalsete mõjudega ning väiksemate investeeringutega (Altieri, 1995). Looduslikes kooslustes on erinevate taimeliikide arv suur. Kooslused on välja kujunenud lähtuvalt keskkonna tingimustest, ühe või teise liigi nõudlusest ja liikidevahelisest konkurentsist (Pork, 1978; Gliessman, 2000). Kultuurkooslused kujunevad aga välja inimtegevuse tulemusel.

Segukülvid on teadliku inimtegevuse tulemus ning need võivad olla nii sortide– kui liikidevahelised, üheaastased, mitmeaastased jm. segud. Mitme erineva kultuuri kooskasvatamisel mõjutavad liigid üksteist vastastikku. See mõju võib olla positiivne, negatiivne või neutraalne. Segukülvides esineb nii liigisisest (näiteks: teravili–teravili, kaunvili–kaunvili) kui liikidevahelist (kaunvili–teravili–umbrohud) konkurentsi (Gliessman, 2000; Powers, McSorley, 2000). Liigisisene konkurents kerkib esile siis kui keskkonna ressursid (mulla toitainete sisaldus, mullavesi) on piiratud (Gliessman, 2000). Kõige ilmekamalt iseloomustab liigisisest konkurentsi taimede külvitihedus, mistõttu maksimaalse saagi saamiseks on oluline tagada taimedele piisav kasvuruum (Powers, McSorley, 2000).

Teadlaste poolt on leitud, et liikidevaheline konkurents väljendub selgemalt seal, kus kasvufaktoreid (taimede poolt omastatavad toitained, mullavesi, päikesekiirgus) ei ole sedavõrd piisavalt, et rahuldada mõlema kultuuri vajadusi (Buxton, Fales, 1993; Gliessman, 2000). Katsete põhjal on selgunud, et segukülvid kasutavad kasvufaktoreid efektiivsemalt kui puhaskülvid (Anil *et al*., 1998; Carr *et al*., 1998). Hauggaard–Nielseni jt. (2001) leidsid, et segukülvide korral kasutati keskkonnaressursse isegi 25–38% efektiivsemalt võrreldes puhaskülvidega. Seetõttu on omavahel

sobivate liikide valik segudesse väga oluline. Valides liigid, millised erinevad üksteisest toitainete, valguse ja vee vajaduse poolest, vähendatakse taimedevahelist konkurentsi ja suurendatakse seeläbi saaki (Powers, McSorley, 2000). Kaun– ja teravilja segukülvid oleks need, millised täiendavad üksteist, on tulemuslikumad ja vastastikuse koosmõju tulemusena väheneb vajadus ka tootmissisendite järele (Jensen, 1996a). Seetõttu kasutatakse kaunvilja–teravilja segukülve rohkem sellistes piirkondades, kus põllumajandustootjate ostujõud on väiksem (Gliessman, 2000).

Suurt mõju segavilja saagile avaldab liikide konkurentsivõime (Caballero *et al*., 1995). Kuigi segukülvis võib kummagi kooskasvatatava kultuuri saak eraldi võetuna konkurentsi tõttu väheneda, on segukultuuri kogusaak tavaliselt kõrgem kui kummagi kultuuri puhaskultuuri saak (Natarajan, Willey, 1980; Altieri, 1995). Kirjanduses on andmeid, et konkurents küll vähendab segukülvide saaki võrreldes teraviljade puhaskülvidega (Caballero *et al*., 1995), kuid kõrgemat saaki saadakse siis, kui konkurentsivõime segukülvis kahe liigi vahel on väiksem kui liigisisene konkurents (Vandermeer, 1989; Vandermeer, 1990).

Kirjanduses leiduvate andmete põhjal võib järeldada, et kaunviljad (vikk, hernes) võivad avaldada teraviljade (nisu, kaer, oder) saagipotentsiaalile väga tugevat negatiivset mõju (Quiroz, Mulas, 2005). Teraviljadest on kõige suurema konkurentsivõimega kaer, talle järgneb nisu ning kõige tolerantsem kaaskultuuride suhtes on oder (Hauggaard–Nielsen *et al*., 2001; Rauber *et al*., 2001). Ceglarek *et al*. (2004) jõudsid järeldusele, et suvivikile oli seemneks kasvatamisel parimaks tugikultuuriks suvitritikale.

2.1.2 Segukomponendid, nende vahekord ning külvitihedus

Viimastel aastatel soovitatakse meie põllumajandustootjatele seoses paremate mullaharimisriistade, täpsemate külvikute ja parema võrsumisvõimega sortide (aretatud Kesk–Euroopas) puhul kasutada mõnevõrra väiksemaid külvisenorme kui on teadlaste poolt varasemate uuringute põhjal soovitatud. See kehtib eriti teraviljade kuid ka rapsi puhul (Mets, 2007; Viil, 2007)

Segukülvide seemnesegude koostamisel tuleb kõigepealt valida, vastavalt kasvatamise eesmärgile (maksimaalne kogusaak, –kaunvilja seemnesaak, haljassööt, haljasväetis jm.), sobivad taimeliigid, sordid ja alles seejärel sobiv külvisenorm. Taimedepoolne erinevate kasvufaktorite kasutamine sõltub suurel määral taimede kasvutihedusest. Selle suurenedes kasvab konkurentsisurve (Powers, McSorley, 2000). Kui taimede tihedus ületab optimaalse piiri või jääb sellest alla, siis saak väheneb (Kallas, 1969). Saaki vähendavad teisedki ebasoodsad kasvutingimused.

Segaviljade optimaalse külvitiheduse osas on erinevaid arvamusi. See sõltub suurel määral segu koosseisust. Sobkowicz ja Śniadu (2000) andmeil kasvatatakse vikki peamiselt koos kaera, nisu, rapsi aga ka suvitritikalega. Meil on suviviki sagedamini esinevaks tugikultuuriks kaer (Reimets, 1993; Lauk, Lauk, 2005). Ühe m^2 kohta on soovitatud külvata 100 viki– ja 400 kaeraseemet (s.o. 50–70 kg viki– ja 130–150 kg kaeraseemet hektari kohta) (Reimets, 1993). Reimets (1993) soovitab veel kuivematel põldudel kasvatatava viki osakaalu segus suurendada, ning tema andmeil annab stabiilsema seemnesaagi viki ja suvirapsi segu, kus on kasutatud vastavalt 100–150 ja 150–200 idanevat seemet m^{-2} kohta. Kaarli (1999) soovitab oma katsetulemuste põhjal, sõltuvalt seemne suurusest, külvata 35–70 kg vikiseemet ha^{-1}, millele võtta lisaks 100–120 kg ha^{-1} kaera. Tugikultuurina vikile soovitab ta kasutada ka nisu ja suvirapsi. EMÜ taimekasvatuse– ja rohumaaviljeluse osakonnas läbi viidud viki–nisu segukülvialaste katsete tulemusena saadi suurim kogusaak väetamata mullal siis, kui seemnesegusse võeti 250 nisu ja 50 viki idanevat seemet m^{-2} (Lauk, Leis, 1997).

Poolas katsetati segukultuuride erinevaid kasvatusmeetodeid, kus liigid külvati alternatiivsetesse külviridadesse, näiteks üks rida tritikalet ja teine vikki või kaks rida tritikalet ja kaks rida vikki. Vikki külvati 150 seemet m^{-2} ning suvitritikalet kas 150 või 300 idanevat seemet m^{-2}. Saagikamaks osutus ribakülv, kus tritikalel oli suurem külvisenorm ja selline ribakülvi variant kus kultuure külvati üle kahe rea (Sobkowicz, Śniadu, 2000).

Kasvutiheduse mõju viki–kaera segukülvides on uuritud erinevates kliimavööndites, kusjuures külvinormid võivad oluliselt erineda. Näiteks soovitatakse Türgis võtta segavilja koostisse 80–135 vikiseemet ja vaid 10–30 tugikultuuri (kaera) tera ruutmeetrile, kusjuures tugikultuuri külvinormi suurendamisel vähenes vikil kaunte arv taime kohta ja seemnesaak, kuigi samal ajal suurenes vikitaimede pikkus (Ozpinar, Soya, 2004).

Hernest kasvatatakse maailma erinevates piirkondades segus paljude kultuuridega. Kirjanduse andmeid kokku võttes võib öelda, et teraviljadest kasutatakse maailmas herne tugikultuurina peamiselt suvinisu, otra, kaera

ning lisaks veel valget sinepit ja suvirapsi. Odrasordid on osutunud sobivaks tugikultuuriks vaid sel juhul, kui segusse ei ole valitud liiga pika varrega hernesorti. Uuringutest on selgunud, et tugikultuur peab olema herne kõrgusest 10–15 cm võrra madalam. Oluline on ka tugikultuuri kasvuaeg – see võib erineda herne kasvuajast mitte enam kui ±5 päeva võrra (Kaarli, 1998).

Eesti Maaviljeluse Instituudis korraldatud katsetes, kus oli eesmärgiks maksimaalse hernesaagi saamine, on osutunud optimaalseks selline seemnesegu, milles hernest oli 40–60 idanevat seemet ja otra ainult 120 idanevat seemet m^{-2}–le. Leiti ka, et sademeterikkal aastal oli herne seisukindlus parem siis, kui kasutati väiksemat herne külvisenormi. Kuival aastal olid tulemused vastupidised, s.t suurem saak saadi herne suurema külvisenormi puhul. Jõuti järeldusele, et tugikultuuri osa suurendamine põhjustab saagis herne osatähtsuse vähenemise ilma et kogusaak suureneks (Kaarli, 1999; Kaarli *et al.*, 1999).

Kalev ja Hindoalla (1990) soovitavad oma katsete tulemusena kasvatada hernest segus teraviljaga vahekorras 50% hernest ja 50% teravilja nende puhaskülvinormist (näiteks: 50 herneseemet ja 300 odra– või kaeratera m^{-2}). Nad leidsid, et sellise komponentide vahekorra puhul mõjutab teravili herne saagikust kõige vähem. Väiksem herne osatähtsus segukülvis ei suudaks leevendada aga valgudefitsiiti söötades.

Poollehetute ja leheliste hernesortide võrdlusest on selgunud, et poollehetutel hernesortidel on herne saagi langus tugikultuuri mõjul suurem kui lehelistel sortidel. Poollehetuid herneid iseloomustab aeglane kasvutempo kasvuperioodi algul, mille tõttu teraviljad suudavad neid rohkem alla suruda kui lehelisi sorte (Kalev, Hindoalla, 1990). Snoadi (1983) arvates on üldse vähetõenäoline, et lehetud herned suudavad teraviljadega edukalt konkureerida, kuna segus olevad taimed on erineva kasvukiirusega ja taimed seetõttu ebavõrdsetes tingimustes. Samuti on leitud, et segukülvides omab herne varrepikkus suuremat tähtsust kui herne lehetüüp ning lühikesevarrelised hernesordid ei sobi näiteks kaeraga kooskasvatamiseks (Rauber *et al.*, 2001).

Brouwer ja Flood (1995) on leidnud, et saagikus sõltub väga suurel määral taimiku lehtede kujust ja asendist. Suurema saagipotentsiaaliga olid püstiste ja kitsaste lehtedega taimed. Sellistel taimedel varjasid ülemised lehed alumisi vähem, mistõttu suurem osa taime lehtede pinnast oli valgusele avatud. See võimaldas aktiivset fotosünteesi suuremal lehestiku pinnal kui horisontaalasendis või longus lehtedega taimedel.

Saksamaal on viidud läbi segukülvide katseid, milliste segusse on võetud 175 idanevat odraseemet ja 40 herneseemet m^{-2}. Nende katsete läbiviimisel leiti, et oder on suure konkurentsivõimega kultuur kuna segukülvidest saadi odralt sama suurt saaki kui puhaskülvidest (Hauggaard–Nielsen, Jensen, 2001; Hauggaard–Nielsen *et al*., 2001).

Leedus korraldatud katsete tulemused näitavad, et herne–odra segukülvis tuleb suurema saagi eesmärgil, olenemata herne sordist, kasutada külvisenormi, kus on seemnesegus 50 kg ha^{-1} hernest ja 150 kg ha^{-1} otra. Teistsugune (75:125) külvisenorm ei osutunud nii efektiivseks (Kažemekas *et al*., 1999).

2.1.3. Lämmastiku omastamine

Toiteelementide olemasolu mullas on üheks oluliseks taimekasvu faktoriks ning toitained peavad olema mullas taimele kättesaadavas vormis. Taimede saagipotentsiaali täielikuks realiseerimiseks on vajalik nii makro– (N, P, K) kui ka mikroelementide (B, Cu, Mo jt.) piisav sisaldus mullas. Üldiselt on teada, et Eesti muldades on esimeses miinimumis tavaliselt lämmastik ning põllukultuuride saagi määrab lämmastiku olemasolu või selle defitsiit mullas. Lämmastiku üldvaru on mineraalmuldades 0,1–0,3%. Seejuures on taimedele omastatav ainult ca 1–3% mullalämmastiku üldvarust, mis on kultuurtaimede kasvatamiseks ebapiisav (Kuldkepp, 1988). Taimed omastavad lämmastikku suures osas nitraat– või ammooniumioonina, eelistades siiski nitraatlämmastikku (Lasa *et al*., 2000). Samas on nitraatide esinemine mullas loodusele suureks ohuks, sest teatud tingimustes võib toimuda nitraatide väljaleostumine mullast ja veekogude saastumine. Väljaleostumise oht tekib juhul kui sügiseks jääb mulda taimede poolt kasutamata nitraatset lämmastikku. Ammooniumlämmastik väljaleostumisele nii kergesti ei allu ja väljaleostuvad kogused on väikesed (Lauk, Turbas, 1988; Lasa *et al*., 2000). Af Geijersstam ja Mårtenssoni (2006) uuringutest on selgunud, et herne–teravilja segukülvid vähendavad lämmastiku leostumist mullast.

Erinevate põllukultuuride lämmastiku vajadused on erinevad, eriti kui võrrelda teravilju kaunviljadega ja ka lämmastiku katteallikad on erinevad.

Teraviljade puhaskülvide kasvatamisel on raske loobuda mineraalsete lämmastikväetiste kasutamisest, sest saagikus ja saagi kvaliteet jääb lämmastiku defitsiidi tingimustes madalaks. Seetõttu soovitataksegi nisu saagi ja saagi valgusisalduse suurendamiseks anda nisule 80–100 kg ha^{-1} mineraalset lämmastikku (Tolstousov, 1976). Maksimaalse proteiinisaagi ja heade kvaliteedinäitajatega saagi saamiseks soovitatakse nisule anda isegi kuni 160 kg ha^{-1} lämmastikku (Tõnissoo, 1995). Kui aga lämmastikväetise hektarinorm ületab 80 kg ha^{-1}, tuleb lämmastikväetist anda jaotatult – osa enne külvi ja osa taimede kasvu ajal. Lämmastikväetise andmine nisu loomisfaasis tagab suurema saagi ja selle suurema proteiinisisalduse. Taimed püsivad kauem rohelised ja omastavad lämmastikku ning sünteesivad orgaanilist ainet pikema perioodi jooksul (Esala, 1991; Tõnissoo, 1995; Kärner, Kärner, 1995). Lämmastikväetise mõju teraviljade saagile ja saagi kvaliteedile sõltub vegetatsiooniperioodi meteoroloogilistest tingimustest. Sademeterikkal vegetatsiooniperioodil suureneb lämmastikväetise mõjul eelkõige nisu saak. Proteiinisisaldus terades muutub vähe. Kuival aastal on olukord vastupidine, suureneb terade proteiinisisaldus, kuid saak muutub väetise mõjul vähe (Tolstousov, 1976).

On teada, et kui väetisi ei kasutata ja liblikõielisi kultuure viljavahelduses ei kasvatata, alanevad mullaviljakus ja saak ning halveneb saagi kvaliteet. Väetiste kasutamisel eri põllukultuuride väetamisel tuleb jääda siiski mõõdukuse piiridesse ning alternatiiviks lämmastikväetistele on liblikõieliste kultuuride aga ka kaun– ja teraviljade segukülvide kasvatamine külvikorras. Sellises olukorras aitaks oluliselt saagi kvaliteeti parandada ja proteiinisaaki suurendada liblikõieliste kultuuride, s.h. viki ja herne kasvatamine koos teraviljaga. Kusjuures on täheldatud, et segukülvid kasutavad lämmastikku 20–30% efektiivsemalt kui puhaskülvid (Hauggaard–Nielsen *et al*., 2006).

Liblikõielistel taimedel toimub esialgne kasv seemnes ja mullas sisalduva mineraalse lämmastiku arvel. Kui välja on kujunenud assimilatsioonivõimeline taimik ja liblikõielistel arenevad juuremügarad, hakkavad taimed toituma õhulämmastiku arvelt. Taim saab bakterite poolt seotud õhulämmastikku ammooniumi näol, bakterid saavad taimelt ühendeid, mis rahuldavad bakterite energiavajaduse (Leokene, 1964; Gliessmann, 2000). Tegelikult rahuldab kaunviljade poolt seotud õhulämmastik kaunviljade enda lämmastikvajaduse (Kaarli, 1999) ja umbes pool seotud lämmastikukogusest jääb varuks järgnevale kultuurile (Sattell *et al*., 1989). Lähtuvalt eelnevast on kaunviljade väetamise kohta väga erinevaid seisukohti.

Väidetakse, et mineraalse lämmastiku andmine kaunviljadele ei ole otstarbekas (suurendab omahinda, lämmastiku leostumise oht jm.) ning enam kui 80 kg ha^{-1} lämmastiku andmine võib pidurdada juuremügarate arengut (Blagoveštšenskoi, 1984). Samas leitakse, et väikeste lämmastikukoguste (kuni 30 kg ha^{-1} lämmastikku) andmine kasvu algul, kui mügarbakterid veel lämmastikku ei seo, on täiesti õigustatud (Reimets, 1993). Katsed on näidanud, et saak on suurem siis kui kaunviljadele anda lämmastikväetisi 60–90 kg ha^{-1} toimeaines. Rohke lämmastik kiirendab lehepinna kujunemist ja intensiivistab fotosünteesi (Reimets, 1986).

Ka pikemaajalistes rohumaauuringute katsetes on leitud, et liblikõieliste taimede kooskasvatamisel kõrrelistega võib teatud osa mügarbakterite poolt seotud õhulämmastikust vabaneda mulda, mida saavad kasutada kõrrelised kas samal või järgnevatel kasvuaastatel. On täheldatud, et valge ristiku poolt seotud õhulämmastik omastati temaga kooskasvanud kõrrelise poolt just teisel ja kolmandal kasutusaastal (Hogh–Jensen, Schjoerring, 2000). Esimesel kasutusaastal ei olnud omastatud lämmastikukogused märkimisväärsed (Hogh–Jensen, Schjoerring, 1997; Jorgensen *et al*., 1999). Kõrreliste poolt omastatud lämmastikukogused olid punase ristiku puhul väiksemad kui valge ristiku puhul. Ristiku lämmastiku omastamist kõrrelisele ei mõjutanud lämmastikuga väetamine ega rohumaa niitmise intensiivsus (Hogh–Jensen, Schjoerring, 1994).

Kaunviljade poolt seotud õhulämmastiku vabanemist mulda ja võimalikku kasutamist teraviljade poolt on uuritud ka kaunviljade ja teraviljade segukülvides. Nii mitmelgi juhul ei suudetud tõestada, et põllu tingimustes omastavad teraviljad kaunviljade poolt seotud õhulämmastikku (Cowell *et al*., 1989; Jensen, 1996a). Nõukatsete baasil läbiviidud uurimistöös siiski selgus, et osa herne poolt fikseeritud õhulämmastikust omastati odra poolt (Jensen, 1996b).

USA teadlase andmetel seob suvivikk keskmiselt 92 kg ja hernes 80 kg lämmastikku hektari kohta aastas (Lewis, 1965). Muelleri ja Thorup–Kristenseni (2001) ning Papastylianou (1999) andmetel seob suvivikk olenevalt aastast 60–100 kg lämmastikku hektari kohta. Mügarbakterite abil lämmastiku sidumise kindlustamiseks tuleb liblikõielise seeme enne külvi inokuleerida vastava mügarbakteri preparaadiga. Suviviki seemnete inokuleerimine suurendas taimede lämmastiku sidumise võimet 28–32% võrreldes mitteinokuleeritud seemnetest kasvatatud taimedega (Ambrazaitiene, 2000). Samas on saadud ka tulemusi, kus nitragiiniga herneseemnete

inokuleerimine ei suurendanud herne saaki (Auskalnis, Dovydaitis, 2000). Õhulämmastiku fikseerimisel ei ole limiteerivaks faktoriks bakterid ise vaid välisfaktorid, mis mõjutavad füsioloogilisi protsesse taimedes (Mengel, 1994). Niisutatavates tingimustes on liblikõielised taimed võimelised siduma õhulämmastiku rohkem (Filek *et al*., 2000). Sõnniku andmine mõjutab vikitaimede kasvu ja soodustab mügarate moodustamist rohkem kui NP–väetistega väetamine (Sidiras *et al*., 1999). Beckann'i andmetel (1997) on viki lämmastikusidumise võime suurem kui ristikul (*Trifolium resupinatum*).

Kaunviljade, s.h. suviviki lülitamist külvikorda peetakse külvikorra üldise produktsiooni suurenemise eelduseks (Yau *et al*., 2003). Küprosel läbi viidud uurimistööst selgus, et vikk on osutunud heaks eelviljaks odrale. Sellega suurenes odra saak ja lämmastiku akumuleerimine odra poolt võrreldes järgnemisega teraviljale (Danso, Papastylianou, 1992; Papastylianou, 1990; 2004).

Orgaanilise maaviljelussüsteemi puhul saab vikki väga edukalt kasutada haljasväetiseks sibulale, kapsale jt. kultuuridele (Willumsen, Thorup–Kristensen, 2001), kuna suviviki biomass laguneb mullas kiiresti (Heinrichs *et al*., 2001). Sooja kliimaga piirkondades kasvatatakse vikki talvel vahekultuurina ja küntakse seejärel sisse haljasväetiseks. Seejuures tehti kindlaks, et sisseküntud haljasmass oli ekvivalentne 137 kg mineraalse lämmastikuga hektari kohta (Aita *et al*., 2001).

3. UURIMISTÖÖ EESMÄRGID

Käeoleva uurimistöö hüpoteesiks oli, et kaunviljade–teraviljade segukülvide sünergiline efekt võib oluliselt sõltuda nii looduslikest teguritest (ilmastik) kui ka inimese poolt loodud tingimustest (erinevad tugikultuurid, külvitihedus, seemnesegu vahekorrad, lämmastikuga väetamine).

1. Uurimistöö käigus sooviti selgitada, mil määral ja kuidas mõjutab segukomponentide (kaunvili–teravili) omavaheline konkurents nende saagipotentsiaali.
2. Leida segukülvide jaoks optimaalne külvisenorm ja komponentide õige vahekord ning sobiv tugikultuur kaunviljadele nende kasvatamisel seemneks või söödaks.
3. Hinnata kaunviljade–teraviljade segukülvide väärtust, kasutades näitajatena seemnesaaki, proteiinisaaki ning saagi proteiinisisaldust ning võrrelda neid teraviljade puhaskülvide näitajatega.
4. Selgitada lämmastikväetise mõju viki–nisu segukülvides komponentide erineva vahekorra juures ning võrrelda seda teraviljade puhaskülvidega.
5. Hinnata meteoroloogiliste tingimuste mõju segaviljade saakidele.

4. UURIMISTÖÖ LÄBIVIIMISE TINGIMUSED JA METOODIKA

4.1. Katsete läbiviimise koht ja katsemetoodika

Uurimistöö baseerub põldkatsetel, millised viidi läbi EMÜ Põllumajandus– ja keskkonnainstituudi katsejaama katsepõldudel Eerikal aastatel 2000 kuni 2004. Katsed rajati vastavalt taimekasvatuse ja rohumaaviljeluse osakonnas varem välja töötatud metoodikale (Lauk *et al.*, 1996; Lauk, 1997) ja on üles ehitatud katseseeriatena. Variandid paiknesid katseseerias randomiseeritult ning ühes korduses, kuna regressioonanalüüs võimaldab välja arvutada katsevea ka ühe korduse olemasolul (Little, Hills, 1972; Mead *et al.*, 1993). Katseseeriate esimene variant oli kõikidel juhtudel kahes korduses, s.o. kahel katselapil, mis võimaldab regressioonanalüüsil paremini kindlaks määrata regressiooni alguspunkti (Lauk, 1994; Lauk, 1995). Ühes katseseerias oli kokku 11 erinevat varianti. Katselappide suurus oli 10 m^2.

Uurimistöö koosneb kahest eraldiseisvast ja oma ülesehituselt erinevast katsest. Esimese katse läbiviimisel oli eesmärgiks sobivate segukülvi kombinatsioonide leidmine ning optimaalse kaunviljade külvisenormi kindlaksmääramine. Katses oli esimestel katseaastatel viis katseseeriat (vt. katsematerjal), 2003. ning 2004. aastal lisandus veel üks katseseeria lämmastikväetise foonil. Kõikides nendes katseseeria variantides võeti teraviljade külvisenormiks 250 idanevat seemet m^{-2}, mis oli varasemate segukülvide uuringute põhjal osutunud optimaalsele lähedaseks (Lauk, Leis, 1997). Kaunvilja külvisenormi muudeti vahemikus 0–120 idanevat seemet m^{-2}, sammuga 12 idanevat seemet m^{-2} (0, 12, 24, 36, 48, 60, 72, 84, 96, 108, 120). Antud metoodika kajastub artiklites **I**, **II** ja **IV**.

Teine katse keskendus ainult viki–nisu segudele. Peatähelepanu pöörati lämmastikväetise mõjule viki ja nisu puhas– ja segukülvides segukomponentide mitmesuguse vahekorra juures. Siin varieerusid viki ja nisu külvisenormid puhas– ja segukülvides 100–500 idaneva seemneni m^{-2} (**V**, tabel 1). Katse oli üles ehitatud kolmeseerialisena: esimeses seerias olid variandid lämmastikväetiseta (N_0) mullal, teises seerias N_{34} foonil ja kolmandas seerias N_{68} foonil (**V**).

Viki–nisu segukülvide tulemuste üldistamisel oli töö autoril lisaks oma andmetele võimalus kasutada segukülvidealaste katsete varasemate aastate andmeid, milles autor ka ise osales. Üldistatud on andmeid aastatest 1994–2004. Välja jäeti aastad 1995, 1996 ja 1998, mil katses olid eelviljaks teised kultuurid. Põhjalikuma vaatluse all oli variant, kus segus oli 50 idanevat vikiseemet ja 250 nisuseemet ruutmeetril ja segukülv järgnes teraviljale (**III**).

4.2. Katsematerjal

Esimeses katses kasutati kaunviljadest suvivikki 'Carolina' ja tavaliselehelist söödahernesorti 'Kirke'. Uuriti vikisordi 'Carolina' kasvatamise võimalusi Eesti tingimustes. Söödahernes valiti varre pikkuse ja kasvuaja järgi, mis oleks võrdlemisi sarnane vikile. Tugikultuurideks valiti meil peamiselt kasvatatavad teraviljaliigid – nisu, kaer ja oder. Teraviljasortide valikul lähtuti teravilja kõrre– ja kasvuaja pikkusest. Neid omadusi arvestades valiti sordilehelt välja suvinisu 'Tjalve', kaer 'Jaak' ja oder 'Elo.

Katseseeriad esimeses katses olid järgmised:
'Carolina'+'Tjalve',
'Carolina'+'Jaak',
2003.– 2004. aastal lisandus 'Carolina'+'Tjalve' lämmastikväetise foonil (N_{50}),
'Kirke'+'Tjalve',
'Kirke'+'Jaak',
'Kirke'+'Elo'.

Teises katses olid kõik katseseeriad vikisordiga 'Carolina' ja suvinisusordiga 'Tjalve'.

4.3. Katsete agrotehnoloogia ja määramised

Eelkultuurina kasvatati kõigil aastatel suvinisu, millele anti lämmastikku arvestusega 60 kg hektari kohta. Antud uurimistöö puhul külvati eri komponentide seemned ühte ja samasse külviritta. Katsed külvati aastatel 2000–2004 vastavalt 25. aprillil, 27. aprillil, 17. aprillil, 7. mail ja 27. aprillil, külviajad sõltusid vastava aasta ilmastikust. Lämmastikväetis (ammooniumnitraat) anti vastavalt katseskeemis ette nähtud variantides vahetult taimede tärkamise järel. Lamandumine tehti kindlaks teraviljade õitsemise järel ja enne koristamist. Kaunviljade tugeva hargnemise tõttu

ja haakumisega teraviljade külge, saagistruktuuri elemente määrata ei olnud võimalik. Saagi koristamiseaeg sõltus kasvuperioodi ilmastikust. Seega koristati saak 2000. aastal nisu–herne ja odra–herne katselappidelt 22. augustil, ülejäänud katselt 28. augustil. 2001. aastal koristati kõik katseseeriad 15. augustil. 2002. aastal koristati kõik katseseeriad kahel üksteisele järgneval päeval s.o. 5. ja 6. augustil. 2003. aastal koristati teravilja–herne katselappidelt 19. ja ülejäänutelt 29. augustil. Katseseeriad teravilja–hernega 2004. aastal koristati 18. augustil ja katseseeriad teravilja–vikiga 24. augustil. Pestitsiide segukülvides ei kasutatud.

Koristamise järel registreeriti terasaagid komponentide lõikes eraldi ja summaarse saagina. Määrati kaunviljade ja teraviljade 1000 seemne massid. Saagiproovide lämmastikusisaldus määrati Eesti Maaülikooli Taimebiokeemia laboratooriumis Kjeldahli meetodil. Lämmastikusisalduse kaudu arvutati saakide proteiinisisaldused kuivaines (koefitsient 6,25) ja proteiinisaagid pinnaühikult.

4.4. Katseala mullastik

EMÜ Põllumajandus– ja keskkonnainstituudi katsejaama Eerika katsepõldudel on kerge liivsavi lõimisega kahkjas muld, millist rahvusvahelise WRB süsteemi järgi nimetatakse *Albeluvisols*. Kahkjate muldade profiil on eluvio–akumulatiivne ja nõrkade liigniiskuse tunnustega, mis agronoomilisest aspektist väljendub kevadise harimisküpsuse saabumise hilinemises mõne päeva võrra (Kõlli, Lemetti, 1999).

Toiteelementide sisaldust huumushorisondis määrati igal aastal EMÜ Taimebiokeemia laboratooriumis. Mulla reaktsiooni poolest (optimaalne kaunviljadele ja nisule pH_{KCl} 6–7) sobisid põllud katses olnud taimeliikide kasvatamiseks enamikel aastatel. 2002. aastal oli põllu künnikihi muld mõnevõrra happelisema reaktsiooniga (pH_{KCl} 4,9–6,1). Liikuva P ja K sisaldus künnikihi mullas on määratud Egner–Rhiemi–Domingo e. AL – meetodil ja see varieerus erinevatel aastatel piirides, vastavalt 74–174 mg kg^{-1} ning 84–204 mg kg^{-1}. Mulla orgaanilise aine sisaldus ei olnud katsepõllu mulla künnikihis kõrge (2,2–3,2%)

4.5. Katseaastate ilmastik

Paljude aastate keskmisele lähedane või mõne kraadi võrra jahedam ja sademeterohke oli suvi 2000. aastal. Sademete summa kasvuperioodil oli 330 mm. Pikaajalise keskmise põhjal on normiks 250 mm.

Järgmisel, 2001. aastal püsisid keskmisest soojemad ilmad kogu vegetatsiooniperioodil. Kogu kasvuperioodi sademete summa oli 285 mm.

2002. aasta vegetatsiooniperioodi võib pidada paljude aastate keskmisest tunduvalt soojemaks ja põuasemaks – sademete summa kasvuperioodil oli ainult 147 mm, mis on ligikaudu 2 korda vähem kui pikaajaline keskmine. Kõik see kiirendas katses olnud taimeliikide ja –sortide arengut. Teraviljad valmisid ligikaudu 25 päeva varem kui tavaliselt.

2003. aastat iseloomustas rohkete sademete esinemine suvel. Segukülvide kasvuperioodil oli sademeid kokku 360 mm. Õhutemperatuur oli paljude aastate keskmisest mõnevõrra jahedam, eriti juunis.

2004. aasta kevad oli suhteliselt kuiv kuni juuni alguseni, seejärel läksid ilmad vihmasemaks. Ka seda aastat tuleb pidada sademeterohkeks, kuna kasvuperioodil sadas kokkuvõttes 420 mm sademeid. Õhutemperatuur püsis paljude aastate keskmise lähedal.

4.6. Andmetöötlus

Andmete statistiline läbitöötlus toimus mõlema katse kõigis katseseeriates regressioonanalüüsi teel. Regressioonanalüüs viidi läbi järgmise üldistava võrrandi abil:

$y = a + bx + cx^2$, milles

y – argumendi funktsioon: saak, proteiinisaak, 1000 seemne mass, proteiinisisaldus jm. (kg ha^{-1} ; g ; %, jm.),

a – võrrandi vabaliige (konstant),

b ja c – regressioonvõrrandi kordajad,

x – argument; argumendiks regressioonanalüüsil võeti kaunviljade külvisenorm ja see varieerus esimeses katses piirides 0–120 idanevat seemet ruutmeetrile. Teises katses oli argumendiks külvisenorm (vikk+nisu), milline varieerus piirides 100–500. Mõningatel juhtudel võib argumendiks olla ka mingi muu põhjuslik tunnus, nt. sademete hulk kasvuperioodil mm.

Vastavalt väljatöötatud metoodikale (Lauk, Lauk, 2000) arvutati kõigile regressioonvõrranditele välja usalduspiirid 95%–lise usutavusega (artiklites tähistatud märgistusega $CL_{0,05}$). Usalduspiiride arvutamisel lähtuti Studenti teoreetilisest kriteeriumist (Mead *et al.*, 1993).

Nisu puhaskülvi ja viki–nisu segukülvi saakide võrdlemisel ning segukülvi efektiivsuse väljatoomisel kasutati lineaarvõrrandit:

$y = a + bx$, milles

y – viki–nisu segukülvi saagierinevus (proteiinisaagi erinevus) kg ha^{-1} võrreldes nisu puhaskülvi saagiga (proteiinisaagiga),

a – võrrandi vabaliige,

b – regressioonikordaja,

x – nisu saak ja nisu proteiinisaak (kg ha^{-1}).

5. TULEMUSED

5.1. VIKI KOOSKASVATAMINE NISU JA KAERAGA

5.1.1. Lamandumine

Taimik ei lamandunud 2000. aastal teraviljade puhaskülvides ja segukülvis viki väikese osatähtsuse juures. Lamandumist segukülvides esines juhul, kui viki külvisenorm oli 60 ja rohkem idanevat seemet ruutmeetri kohta.

2001. aastal kasvas taimik lopsakam kui eelmisel aastal ning peale 16. ja 17. juuli tugevat paduvihma lamandusid segukülvide katselapid tugevasti. Täiesti püstine oli taimik teravilja puhaskülvis ja segukülvi lappidel juhul, kui kaunvilja külvisenorm oli 12 idanevat seemet m^{-2}. Mida suurem oli kaunviljade osatähtsus seemnesegus, seda intensiivsemalt oli taimik lamandunud.

Põuasel 2002. aastal õnnestus saaki saada tänu varajasele külvile. Kaunviljad jäid segukülvides teraviljadega alarindesse, mistõttu segukülvid ei lamandunud.

Sademeterikkamatel aastatel (2003 ja 2004) esines katsetes tugevamat segukülvide lamandumist alates kaunviljade külvisenormist 60 idanevat seemet ruutmeetril. Koristamiseni jäid lamandumata teraviljade puhaskülvid ja segukülvide variandid, milliste puhul kaunvilju võeti teravilja hulka arvestusega 12 idanevat seemet m^2 kohta. Keskmiselt (taimede kõrred ja varred 45° nurga all maapinna suhtes) olid lamandunud variandid, millistes kaunviljade külvisenorm oli 24, 36 ja 48 idanevat seemet ruutmeetrile. Lämmastikuga väetamine (N_{50}) vähendas mõnevõrra segukülvide lamandumist.

5.1.2 Seemnesaagid

Sademeterohketel aastatel (2003–2004) oli viki saagikus teraviljade segudes kõrge juba väikestel viki külvisenormidel. Viki külvisenormil 20 idanevat seemet m^{-2} oli viki saak, olenevalt katseseeriast, piirides 1420–1770 kg ha^{-1} (**IV**, tabel 1). Viki saaki vähendas kontrollseeriaga (vikk+nisu N–väetiseta mullal) võrreldes nimetatud viki külvisenormi juures nii lämmastikuga väetamine (N_{50}) kui ka kooskasvatamine kaeraga. Väikseimad vikisaagid saadigi viki väikestel külvisenormidel kooskasvatamisel kaeraga. Viki külvisenormi suurenemisel lämmastikväetise ja kaera negatiivne mõju viki seemnesaakidele vähenes ning maksimaalse viki külvisenormi juures puudus. Kui viki külvisenorm oli 60 seemet m^{-2}, saadi viki saagiks kooskasvatamisel nisuga 2152 kg ha^{-1} ja kaeraga 1964 kg ha^{-1}.

Teraviljade puhaskülvide võrdlus näitas, et kaer andis suuremat saaki kui nisu. Kaer ületas saagikuse poolest nisu ka segukülvides vikiga. Seejuures saadi kaera teri puhaskülvis 3013–3050 kg ha^{-1} (**II**, tabel 1; **IV**, tabel 1). Nisu puhaskülvis oli saak kaera puhaskülviga võrreldes usutavalt väiksem isegi juhul, kui nisule anti 50 kg lämmastikku hektarile ($p<0,05$). Eriti suur oli saagierinevus (1115 kg ha^{-1}) nisu kahjuks sademeterikastel aastatel, siis jäi terasaak nisu puhaskülvis lämmastikväetiseta mullal suhteliselt madalaks (2400 kg ha^{-1}). Viki võtmine teravilja seemne hulka ja viki külvisenormi suurendamine avaldas negatiivset mõju teraviljade saagipotentsiaalile (korrelatsioonikoefitsient $R=0,980–0,998$; $p<0,001$). Teraviljade terasaagi vähenemine seoses viki külvisenormi suurenemisega oli märkimisväärne kõigil juhtudel (vähenemine 2000.–2002. aasta keskmisena nisul maksimaalselt 1861 kg ja kaeral 1413 kg hektari kohta; 2003.–2004. aasta keskmisena nisul lämmastikväetiseta foonil 1680 ja nisul N_{50} foonil 1804 kg võrra ning kaeral 2317 kg võrra hektari kohta) (**II**, tabel 1; **IV**, tabel 1).

2000.–2002. aasta keskmisena, mil sademeid oli vähem, moodustus maksimaalne viki–teraviljade segukülvide saak (2813–3156 kg ha^{-1}) viki väikseima külvisenormi juures, mis oli küllalt lähedane teraviljade puhaskülvide saakidele (2783–3013 kg ha^{-1}; **II**, tabel 1). Järgneval kahel sademeterikkal aastal moodustusid maksimaalsed segukülvide saagid (2882–3814 kg ha^{-1}) viki külvisenormil 40–50 idanevat seemet m^{-2} (**IV**, tabel 1). Viimasel juhul oli viki–nisu ja viki–kaera segukülvi saak maksimaalse saagitaseme juures vastavalt 950 ja 760 kg võrra hektarilt suurem kui vastavate teraviljaliikide puhaskülvis. Lämmastikuga väetamisel (N_{50}) saadi võrreldes nisu puhaskülviga viki–nisu segukülvist 800 kg võrra suuremat saaki hektarilt viki külvisenormil 60 seemet m^{-2}. Seosed viki külvisenormi ja segukülvide saagi vahel olid väga tihedad ($R=0,878–0,980$; $p<0,001$). Viki–kaera segukülvides oli saak 343–972 kg võrra hektarilt suurem kui viki–nisu segukülvides ($p<0,05$). Seejuures, viki–kaera segukülvi suurem saak formeerus kaera suurema saagi arvel.

Üldistades pikema perioodi jooksul (aastad 1994–2004) saadud tulemusi võib öelda, et kui konkreetsed kasvukoha tingimused ja muud taimekasvufaktorid võimaldavad nisu puhaskülvist saada saake üle 3000 kg ha^{-1} kohta, siis viki–nisu segukülvid kaotavad saagi osas oma eelise nisu puhaskülvide ees, kuna annavad väiksemat saaki. Vaatluse all olnud 14 variandi saagianalüüs näitas, et vaid kolmel aastal oli segukülvi saagitase veidi suurem nisu puhaskülvi saagitasemest (**III**, joonis 1). Neil aastail kui nisu puhaskülvi saagitase oli madalam ja jäi vahemikku 1500–3000 kg ha^{-1} saadi kõikidel juhtudel viki–nisu segukülvides suuremat saaki kui nisu puhaskülvidest. Viki–nisu segukülvid tagasid 3000 kg hektarisaagi juhul, kui sademete summa kasvuperioodil oli 300±50 mm (**III**, joonis 2).

5.1.3. 1000 seemne massid

Viki võtmine teravilja seemne hulka ning viki külvisenormi suurendamine vähendas tunduvalt teraviljade 1000 tera massi (R=0,958–0,988; p<0,001), mis oli ühtlasi teraviljadel üheks saagilanguse põhjuseks (**II**, tabel 1; **IV**, tabel 3). Teraviljade 1000 tera massi vähenemine seoses viki külvisenormi suurenemisega oli kõigil juhtudel küllalt suur ning 2000–2002. aastate keskmisena vähenes see nisul kuni 6,3 g võrra, kaeral aga 2,5 g võrra. 2003.–2004. aastate keskmisena vähenes see nisul kuni 10,8 g võrra ja kaeral 12,7g võrra.

5.1.4. Seemnesaakide proteiinisisaldused ja proteiinisaagid

Aastate 2000–2002 analüüs näitas, et keskmisena oli nisu– ja kaeraterade proteiinisisaldus puhaskülvis vastavalt 13,7 ja 11,4% kuivaines (**II**, tabel 2). Teraviljade terade proteiinisisaldus suurenes oluliselt seoses viki külvisenormi suurenemisega (R=0,956–0,992; p<0,001) ning oli maksimaalne viki külvisenormil 120 idanevat seemet m^{-2}. Nisu– ja kaeraterade proteiinisisaldus tõusis vastavalt 2,5% ja 1,5% võrra. Teraviljade terade proteiinisisalduse võrdlus segukülvides näitas, et üldjuhul oli nisuterade proteiinisisaldus kaeraterade omast 2,3–4,0% võrra suurem. Vikiseemnete proteiinisisaldus oli kõikide aastate keskmisena piirides 31,1–31,4% kuivaines.

Kui teraviljade proteiinisaagid pinnaühikult olid suurimad puhaskülvides (**II**, tabel 2), siis viki võtmine teraviljade seemne hulka ja külvisenormi suurendamine mõjus negatiivselt teraviljade proteiinisaakidele (teraviljade

terasaagis sisalduvale lämmastikukogusele). Seosed on väga tugevad ja usutavad (R=0,966–0,996; p<0,001). Nisu ‘Tjalve’ proteiinisaak vähenes aastate 2000–2002 keskmisena segukülvis vikiga kuni 3 korda, kaera ‘Jaak’ proteiinisaak vähenes kuni 1,7 korda. Samas sisaldasid kaerasaagid kolme aasta keskmisena puhaskülvis ja viki väiksematel külvisenormidel vähem proteiini kui nisusaagid. Suuremate viki külvisenormide korral oli olukord vastupidine.

Viki–teraviljade segukülvid osutusid efektiivseks proteiinisaagi seisukohalt. Viki võtmine teravilja seemnete hulka suurendas oluliselt proteiinisaake (R=0,862–0,952; p<0,001), mis olid võrreldes teraviljade puhaskülvide saakidega, suuremad juba viki väiksematel külvisenormidel. Maksimaalsed proteiinisaagid saadi viki–nisu segukülvis (500 kg ha^{-1}) ja viki–kaera segukülvis (436 kg ha^{-1}) siis, kui viki külvisenormiks oli 60 idanevat seemet ruutmeetrile (**II**, tabel 2). Järgnev viki külvisenormi suurenemine tõi kaasa proteiinisaagi languse segukülvides.

Üldistades pikema perioodi (aastad 1994–2004) andmeid, selgus et viki–nisu segukülvidel on proteiinisaagi moodustajana eelis nisu puhaskülvide ees, mille põhjuseks on viki kõrge proteiinisisaldus (**III,** joonis 3). Katsetes olid nisu puhaskülvi proteiinisaagid ümmardatult vahemikus 175–480 kg ha^{-1}. Segukülvist tulenev proteiinisaagi täiendav laekumine oli võrreldes nisu puhaskülviga meie uurimuses 100–500 kg ha^{-1} ning sõltus suuresti nisu puhaskülvi potentsiaalsest proteiinisaagi võimest. Olukorras kus lämmastiku defitsiidi tõttu jäävad nisu saagid ja proteiinisaagid madalaks, kindlustavad viki–nisu segukülvid teraviljale järgnemisel 600–700 kilogrammilise proteiinisaagi hektarilt (**III,** joonis 3).

5.2. HERNE KOOSKASVATAMINE NISU, KAERA JA ODRAGA

5.2.1. Lamandumine

2000. aastal teraviljade puhaskülvides ja herne väikese osatähtsuse juures segukülvides taimed katselappidel ei lamandunud. Lamandumist segukülvides esines juhul, kui herne külvisenorm oli 48 ja rohkem idanevat seemet ruutmeetri kohta.

Ülejäänud aastatel sarnanes herne–teravilja segavilja katselappide lamandumine viki–teravilja katselappidele (vt. alapeatükk 5.1.1.).

5.2.2. Seemnesaagid

Seemnesaake mõjutas oluliselt ilmastik. Sademeterohketel aastatel (2003–2004) oli herne saagikus segukülvides suur (714–860 kg ha^{-1}) juba herne väiksemate külvisenormide puhul (**IV**, tabel 2). Mida suurem oli herne külvinorm, seda kõrgem oli hernesaak ning herne maksimaalne saak 2120–2330 kg ha^{-1} saadi kooskasvatamisel teraviljadega siis, kui külvisenorm oli 120 idanevat seemet m^{-2}. Kooskasvatamisel kaeraga oli herne saak usutavalt väiksem kui kooskasvatamisel nisuga. Viki ja hernesaakide omavaheline võrdlus külvinormil 20 idanevat seemet m^{-2} näitas, et hernesaak oli siiski ligikaudu 2 korda väiksem kui viki saak.

Maksimaalne saak kõigil katseaastail iga teraviljaliigi puhul saadi puhaskülvidest, kusjuures suurim keskmine saak oli kaeral, see varieerus aastati 2813–3155 kg ha^{-1} (**I**, tabel 1; **IV**, tabel 2). Nisu ja odra saak samasugustes tingimustes oli kaeraga võrreldes vastavalt 604–641 kg ja 937 kg võrra hektarilt väiksem. Herne võtmine teravilja seemnete hulka vähendas teraviljade saagikust, kusjuures mida suurem oli herne külvisenorm, seda väiksem oli teraviljade saagikus (R=0,965–0,993; p<0,001). Teraviljasaakide omavahelisel võrdlusel selgus, et kaera terasaak vähenes herne osatähtsuse suurenedes teiste teraviljaliikidega võrreldes kõige vähem (2000–2002. aasta keskmisena kuni 1413 kg võrra hektari kohta; sademeterikaste 2003.–2004. aastate keskmisena kuni 1512 kg võrra hektari kohta).

Analüüsides kuivemate aastate (2000–2002) saake selgus, et maksimaalne kogusaak saadi kaera–herne segukülvist (3388 kg ha^{-1}) siis, kui herne külvisenorm oli 60 idanevat seemet m^{-2} (**I**, tabel 1). Võrreldes kaera puhaskülviga oli herne–kaera segukülvi saak hektarilt 233 kg võrra suurem. Nisu–herne segukülvist saadi maksimaalne kogusaak (2776 kg ha^{-1}) herne külvisenormil 40 idanevat seemet m^{-2} ning saak oli sel juhul nisu puhaskülviga võrreldes 225 kg võrra hektarilt suurem. Odra–herne segukülvi saak aga odra puhaskülvi saaki ei ületanud.

Sademeterikaste aastate (2003–2004) keskmisena saadi maksimaalne kogusaak (2862 kg ha^{-1}) herne–nisu segukülvist herne külvisenormil 80 idanevat seemet m^{-2}. Herne kooskasvatamisel kaeraga oli maksimaalne saak (3500 kg ha^{-1}) herne külvisenormil 70 idanevat seemet ruutmeetril (**IV**, tabel 2). Herne–teraviljade segukülvidest saadi 680–690 kg võrra suuremat saaki hektarilt kui nisu ja kaera puhaskülvidest.

Andmeanalüüs näitas, et seosed herne külvisenormi ja segukülvi kogusaagi vahel olid tugevad ja usutavad kombinatsioonides nisu+hernes ja oder+hernes (R=0,679–0,977; p<0,05 ja p<0,001) sademeterohkematel aastatel ning seos oli nõrk ja mitteusutav kuiva suvega aastatel (2000–2002) kombinatsioonis kaer+hernes (R=0,526; p>0,05). Suurimat saaki andis teiste teraviljasegudega võrreldes kõikidel herne külvisenormidel kaera–herne segu. Saagierinevus, võrreldes nisu–herne segukülviga oli 487–700 kg ha^{-1}, sõltudes herne külvisenormist (**I**, tabel 1). Seejuures kaera–herne segukülvi suurem saak formeerus kaera kui vähemnõudlikuma kultuuri arvelt. Odra–herne segukülvi saak oli kaera–herne ja nisu–herne segukülvide saakidest tunduvalt madalam.

5.2.3. 1000 seemne massid

Herne võtmine segusse ning herne külvisenormi suurendamine vähendas tunduvalt teraviljade 1000 tera massi. Kuivemate aastate (2000–2002) keskmisena oli odral kuni 6,6 g võrra, nisul kuni 2,8 g võrra ja kaeral kuni 1,7 g võrra väiksem 1000 tera mass (**I**, tabel 2). Sademeterikaste aastate (2003–2004) keskmisena oli teraviljade 1000 tera massi vähenemine suurem, nisul kuni 3,2 g ning kaeral kuni 4,1 g (**IV**, tabel 3). Seosed herne külvisenormi ja teraviljade 1000 tera massi vahel olid väga tugevad ja usutavad (R=0,847–0,984; p<0,001).

5.2.4. Seemnesaakide proteiinisisaldused ja proteiinisaagid

Katsetest selgus, et 2000–2002. aasta keskmisena oli puhaskülvis nisuterade proteiinisisaldus 14,1% kuivaines, kaeral ja odral, vastavalt 11,9% ja 12% kuivaines (**I**, tabel 2). Segude proteiinisisalduse määramisel selgus, et mida kõrgem oli herne külvisenorm segus, seda suurem oli kõikide segudes olnud teraviljade terade proteiinisisaldus. Seosed herne külvisenormi ja terade proteiinisisalduse vahel olid väga tugevad ja usutavad (R=0,956–0,974; p<0,001). Segudes olnud teraviljade omavaheline võrdlus näitas, et puhaskülviga võrreldes suurenes kõige enam nisuterade proteiinisisaldus (kuni 2,6%) ning see oli sõltuvuses herne külvisenormist. Järgnes oder (kuni 1,7%) ning kaera puhul oli proteiinisisalduse suurenemine terades väikseim (kuni 1,2%). Herne proteiinisisalduse analüüs näitas, et see oli kolme aasta ja kõikide katsevariantide keskmisena 24,2%.

Seoses suurema terasaagiga saadi ka suurimad teraviljade proteiinisaagid pinnaühikult teraviljade puhaskülvidest (**I**, tabel 3). Herne lisamine teraviljadele ja herne külvisenormi suurendamine mõjutas negatiivselt kõikide segudes olnud teraviljade proteiinisaake väga tugevasti ja usutavalt (R=0,952–0,984; p<0,001). Kolme aasta keskmisena vähenes herne külvisenormi suurenedes proteiinisaak kõige rohkem nisul – kuni 168 kg võrra hektari kohta. Suuremaid proteiinisaake nii puhas– kui segukülvis saadi kaeralt. Olenevalt herne külvisenormist oli kaera proteiinisaak nisu proteiinisaagist 11–80 kg võrra hektarilt suurem. Väiksemat proteiinisaaki saadi võrreldes nisu ja kaeraga odralt.

Herne–teravilja segu osutus proteiinisaagi seisukohalt efektiivseks (**I**, tabel 3), sest siin lisandus teraviljaproteiinile herneproteiin. Kuivõrd hernes on proteiinirikkam kui teravili, siis herne külvisenormi suurendamine suurendas oluliselt segukülvide proteiinisaake (R=0,804–0,967; p<0,01 ja p<0,001). Külvisenormi suurendamisel olid siiski omad piirid. Nii suurenesid segukülvide proteiinisaagid herne–teraviljade segukülvides kuni herne külvisenormini 80 idanevat seemet m^{-2}. Maksimaalne proteiinisaak, 490 kg ha^{-1} saadigi kaera–herne segukülvist samal külvisenormil. Järgnev herne külvisenormi suurendamine tõi kaasa hoopiski proteiinisaagi languse. Segude omavaheline võrdlus näitas, et proteiinisaak oli suurim kombinatsioonis kaer+hernes. Herne–kaera segukülvi proteiinisaak oli 168 kg võrra hektarilt suurem kui kaera puhaskülvi puhul. Kombinatsioonis nisuga oli segukülvi maksimaalne proteiinisaak 453 kg ha^{-1}. Odra–herne segukülvi proteiinisaagid jäid tunduvalt väiksemaks (maksimaalselt 316 kg ha^{-1}).

5.3. LÄMMASTIKVÄETISE MÕJU VIKI–NISU SEGUKÜLVIDES

5.3.1. Seemnesaagid

Lämmastikväetise mõju uuringud viki–nisu segukülvidele viidi läbi teise katse raames 2000. ja 2001. aastal. Katsetulemuste põhjal selgus, et mõlemal aastal saadi väetamata mullal (kontrollvariant, N_0) nisu puhaskülvist suhteliselt kõrget ja stabiilset saaki, vastavalt 3380 kg ha^{-1} ja 3360 kg ha^{-1}. Võrreldes nisu ja viki puhaskülvide saake väetamata mullal, selgus et nisu puhaskülvi terasaak oli ligikaudu 1,7 korda suurem kui viki puhaskülvi terasaak (**V**, tabel 2). Lämmastikuga väetamine suurendas saagierinevust

veelgi. Katsetest selgus, et viki puhaskülvis oli lämmastikväetise mõju negatiivne, nisu puhaskülvis saadi aga lämmastikväetise mõjul suurt enamsaaki (sõltuvalt lämmastiku normist 306–639 kg ha^{-1}) võrreldes väetamata variandiga. Lämmastikväetise mõju nisu saagile oli tuntavam 2000. aastal, mil suurem lämmastikväetise norm suurendas saaki 1000 kg võrra hektari kohta. Kahe aasta keskmisena oli lämmastikväetise (N_{68}) keskmine efektiivsus nisu puhaskülvis 9,4 kg teri 1 kg lämmastiku kohta.

Viki saaki mõjutas olulisel määral ilmastik. Mõnevõrra niiskem 2001. aasta sobis viki kasvuks paremini ja viki saak puhaskülvis oli väetamata mullal 2460 kg ha^{-1}. Kuivemal 2000. aastal viki puhaskülvi saak jäi väetamata mullal eelmise aastaga võrreldes madalaks (1375 kg ha^{-1}). Lämmastiku mõju hindamisel viki saagile selgus, et nii kahe aasta keskmisena kui ka mõlemal konkreetsel katseaastal avaldas lämmastikväetisega väetamine negatiivset mõju viki seemnesaagile nii puhas– kui segukülvides (**V**, tabel 2). Lämmastikväetise negatiivne mõju viki seemnesaagile suurenes siis, kui seemnesegus vähendati viki külvisenormi ja nisu külvisenormi suurendati. Eriti suur oli lämmastikväetise negatiivne mõju viki terasaagile viki kasvuks soodsamal 2001. aastal. Viki saak vähenes märgatavamalt just kõrgema lämmastikukoguse ($N_{68)}$) juures ning see vähenemine (208–560 kg võrra hektari kohta) sõltus otseselt ka viki külvisenormist. Esimeses katses oli üheks katseseeriaks 2003. ja 2004. aastal viki–nisu segukülvi puhul lämmastikväetise foon (N_{50}). Tulemustest selgus, et lämmastikväetise mõju viki saagikusele sõltus viki külvisenormist (**IV**, tabel 1). Väiksemate viki külvisenormide juures (kuni 60 seemet m^{-2}) oli lämmastikväetise mõju viki seemnesaagile negatiivne. Samas katseseerias (N foon) saadi viki–nisu segukülvi lämmastikuga väetamisel maksimaalne saak (veidi üle 3200 kg ha^{-1}) viki külvisenormil 60 seemet m^{-2} ja segukülvi saak oli 800 kg võrra hektarilt suurem kui nisu puhaskülvis samasugustes tingimustes (**IV**, tabel 1).

Teise katse tulemuste analüüsil selgus, et katseaastate (2000–2001) keskmisena saadi väetamata mullal viki–nisu segukülvides suuremat saaki kui viki puhaskülvist (**V**, tabel 2). Nisu puhaskülvist aga mõnevõrra suuremat saaki saadi väetamata mullal sellise segu korral, kus vikki oli võetud seemnesegusse 12 ja nisu 438 idanevat seemet ruutmeetrile. Lämmastikuga väetamisel (N_{34}, N_{68}) suurenes viki–nisu segukülvis oluliselt nisu saagikus, samal ajal kui väetise mõju segukülvi kogusaagile oli väiksem, sest lämmastik vähendas segukülvis viki saagikust. Mõlemal aastal eraldi võetuna ja ka kahe aasta keskmisena olid seosed segukülvi külvisenormi (ühtlasi ka komponentide vahekorra muutumisel seemnesegus) ja segukülvi saagi vahel väga tihedad. Kahe aasta keskmisena oli R väärtus, sõltuvalt lämmastiktoitumise tasemest, piirides 0,968–0,966; p<0,001.

5.3.2. Nisu–viki 1000 seemne massid

Katsetest selgus, et viki 1000 seemne mass sõltus oluliselt külvisenormist ja komponentide vahekorrast seemnesegus (**V**, tabel 3). Seejuures oli väetamata mullal seos külvisenormi ja viki 1000 seemne massi vahel väga tihe (R = 0,938; p<0,001). Kõige väiksemaks osutus viki 1000 seemne mass viki puhaskülvis. Segukülvis oli viki 1000 seemne mass seda suurem, mida vähem võeti vikki seemnesegusse. Lämmastikväetise mõju viki 1000 seemne massile oli vastuoluline, mistõttu olulisi seaduspärasusi on raske välja tuua. Lämmastikväetise väiksema normi (N_{34}) mõju viki 1000 seemne massile oli negatiivne viki väiksema osatähtsuse puhul seemnesegus. Lämmastkväetise suurema normi (N_{68}) mõju viki 1000 seemne massile segukülvides ei olnud usutav.

Nisu 1000 tera mass sõltus samuti oluliselt segukülvi külvisenormist ja segukomponentide vahekorrast seemnesegus (väetamata mullal R = 0,985; p<0,001). Suurim oli nisu 1000 tera mass puhaskülvis. Nisu 1000 seemne mass vähenes oluliselt seoses viki osatähtsuse suurenemisega seemnesegus. Kui nisu 1000 tera mass väetamata mullal vähenes kuni 6 g võrra seoses viki osatähtsuse suurenemisega, siis viki 1000 seemne mass vähenes seoses viki osatähtsuse suurenemisega taimikus kuni 12 g. Lämmastikväetise mõju nisu 1000 tera massile oli positiivne, millega on seletatav osaliselt ka nisu terasaagi suurenemine lämmastikväetise mõjul (**V**, tabel 3).

5.3.3. Seemnesaakide proteiinisisaldused ja proteiinisaagid

Vikiseemnete proteiinisisaldus ei sõltunud kuigivõrd ei lämmastikväetisest, külvisenormist ega komponentide vahekorrast seemnesegus ning püsis piirides 30,0–30,6% kuivaines (**V**).

Seevastu nisuterade proteiinisisaldus sõltus kahe aasta keskmisena oluliselt külvisenormist ja komponentide vahekorrast seemnesegus (R = 0,983–0,999; p<0,001). Kõige väiksem oli nisuterade proteiinisisaldus

nisu puhaskülvis, 12,4% kuivaines (**V**, tabel 4). Segukülvides nisu proteiinisisaldus suurenes märkimisväärselt ning oli seda kõrgem, mida rohkem võeti seemnesegusse vikki. Lämmastikuga väetamine mõjutas nisuterade proteiinisisaldust mitu korda vähem kui külvisenorm. Samal ajal aga oli nisu puhaskülvis lämmastiku mõju terade proteiinisisaldusele positiivne ja sõltus otseselt lämmastikväetise normist.

Segukülvi saagi proteiinisisaldus oli tunduvalt kõrgem kui nisu puhaskülvi saagi proteiinisisaldus isegi siis, kui vikki võeti seemnesegusse suhteliselt vähe. Lämmastikväetise kasutamine tõi kaasa segukülvide saagi proteiinisisalduse vähenemise, mis tulenes viki osatähtsuse vähenemisest segukülvi saagis.

Katsetulemuste põhjal võib märkida, et väetamata mullal annavad viki puhaskülvid üldjuhul suuremat proteiinisaaki (502 kg ha^{-1}) kui nisu puhaskülvid (369 kg ha^{-1}; **V**, tabel 4). Kusjuures lämmastikväetise mõju viki proteiinisaagile oli nii mõlemal aastal eraldi kui ka kahe aasta keskmisena negatiivne. Nisust komponendi proteiinisaak aga suurenes lämmastikväetise mõjul märkimisväärselt ning lämmastikväetise normi suurendamine suurendas ka nisu proteiinisaaki.

Aastate keskmisena saadi suurim proteiinisaak viki–nisu segukülvidest. Segukülvi proteiinisaak sõltus oluliselt külvisenormist ja komponentide vahekorrast seemnesegus (R = 0,999; p<0,001). Maksimaalne proteiinisaak (584 kg ha^{-1}) lämmastikväetiseta mullal saavutati siis kui külvisenormiks oli 250 idanevat seemet ruutmeetri kohta (sealhulgas 64 vikiseemet ruutmeetrile). Kuna segukülvi üksikute komponentide reageering lämmastikväetise kasutamisele oli vastupidine (nisul positiivne, vikil negatiivne), siis oli väetise mõju segukülvi proteiinisaagile suhteliselt tagasihoidlik ja väiksema lämmastikväetise normi puhul mitteusutav. Mõnevõrra suuremat lämmastikväetise mõju võis täheldada suurema lämmastikväetise normi (N_{68}) puhul, kui segukülv sisaldas põhilises osas nisu millele oli juurde võetud 12 idanevat seemet m^{-2} vikki. Kui lähtuda proteiinisaakidest, siis saab viki–nisu segukülve kasvatada ilma lämmastikväetiseta.

6. ARUTELU

6.1 Viki või herne kasvatamise võimalusi koos erinevate teraviljaliikidega

Käesolevast uurimistööst selgus, et segukülvi komponentide vahel (milleks olid tera– ja kaunviljad) valitses tugev liikidevaheline konkurents, mis ei lasknud realiseeruda kummagi liigi saagipotentsiaalil. Analoogsele järeldusele on jõudnud teisedki teadlased, ehkki nende katsetes on olnud teiste kultuuride segud (Natarajan, Willey, 1980; Altieri, 1995). Väetamine lämmastikväetisega suurendas segukülvide saaki, sest viki–nisu segus suurenes nisu konkurentsivõime (**IV**, tabel 1; **V**, tabel 2). Selles osas kattuvad meie andmed mitme varasema uurimistöö tulemusega, mis samuti näitavad, et lämmastikväetise abil on võimalik suurendada segukülvi saake (Osiru, Willey, 1972; Cordero, McCollum, 1979). Saagi suurenemise kõrval põhjustas lämmastikuga väetamine viki seemnesaagi vähenemist (**IV**, tabel 1; **V**, tabel 2). Ilmselt on see tingitud väetamise mõjul suurenenud nisu konkurentsivõimest viki suhtes, sest sarnase tulemuse on samas katsekohas andnud ka mitmed varasemad katsed (Lauk, Leis, 1997).

Uurimistöös kasutasime segukomponendina lehelist hernest. Sellisel valikul lähtusime Jõgeva Sordiaretuse Instituudis saadud tulemustest, et lehelistel hernesortidel on saagilangus segukülvis väiksem kui poollehetutel sortidel (Kalev, Hindoalla, 1990). Ka leidus kirjanduses andmeid selle kohta, et poollehtetud hernesordid on segude koosseisus väiksema konkurentsivõimega (Tofinga *et al*., 1993). Näiteks on Snoadi (1983) väitnud, et lehetud hernesordid ei suuda teraviljaga konkureerida ning nende kasutamine segus teraviljadega ei anna soovitud tulemusi. Kuid on ka leitud, et tähtsust ei oma mitte niivõrd herne lehetüüp kuivõrd herne varre pikkus ning Rauber jt., (2001) soovitavad segukülvidesse kaeraga valida just pikemavarrelisi hernesorte. Meie uurimistulemused näitasid, et tõepoolest katses olnud pikavarreline hernesort 'Kirke' avaldas segukülvis tugevat negatiivset mõju tugikultuuri terasaagile.

Kirjanduses on valdav seisukoht, et segukülvidest saadakse tavaliselt suuremat saaki kui kummagi kultuuri puhaskülvist (Altieri, 1995). Seda on näidanud ka mitmed katsed, kus kaunviljade–teraviljade segukülvid on olnud aastate lõikes mõnevõrra stabiilsema saagiga kui komponentide puhaskülvid (Willey, 1979; Ofori, Stern, 1987). Antud töö tulemustest selgus, et viki–nisu segukülvide sünergiline efekt ei ilmnenud

(st. segukülvidest ei saadud suuremaid kogusaake kui nisu puhaskülvidest) juhul kui nisu saagitase puhaskülvis oli üle 3000 kg ha^{-1} (**III**, joonis 1). Suurt sünergilist efekti andsid viki–nisu segukülvid kui nisu puhaskülvi saagitase jäi lämmastikväetiseta mullal vahemikku 1500–2500 kg ha^{-1}. Üldiselt tõi 1 kg nisu terasaagi muutus enesega kaasa 0,96 kg muutuse viki–nisu segukülvide efektiivsuses st., et kui nisu puhaskülvi saak suureneb 1 kg võrra, siis nisu–viki segukülvi erinevus võrreldes nisu puhaskülviga vähenes 0,96 kg võrra. Viki puhaskülvi saak samades tingimustes on nisu järel lämmastikväetiseta mullal jäänud alla 2300 kg ha^{-1} (**V**, tabel 2; Lauk *et al*. 1999b).

Teiseks oluliseks põhjuseks, mis võib takistada kaun–ja teraviljade segukülvide positiivse koostoime ilmnemist, on meteoroloogilised tingimused kasvuperioodil. On täheldatud, et kuival aastal jääb segukülvis madalaks just kaunviljast komponendi saak (Reimets, 1969; Guilioni *et al*., 2003). Tõestamaks ilmastiku mõju segukülvidele, analüüsiti antud töö käigus võrdlevalt sarnaste eelnevate aastate katsete tulemusi. Vaatluse alla võeti katseseeriatest variant, millise puhul oli seemnesegu vahekord 50 idanevat vikiseemet ja 250 idanevat nisutera m^2 kohta. Välja toodi seos sademete hulga ja segukülvi saagi vahel ning see haarab aastaid 1994–2004. Leiti, et seos on väga tugev (R=0,958; p<0,001) ja kehtib ainult siis kui segukülvi kasvatatakse teravilja järel (**III,** joonis 2). Antud töö tulemustest järeldub, et teravilja järel kasvatamisel on viki–nisu segukülvil ligikaudu 3000 kg hektarisaak tagatud juhul, kui sademete summa kasvuperioodil on 300±50 mm (**III,** joonis 2). Andmete analüüs näitas, et kõige kuivem oli 1999. aasta, mil taimekasvu perioodil sademete summa oli alla 100 mm ja keskmine õhutemperatuur normist kõrgem. Sellistes tingimustes lõpetas vikk segaviljas kasvu varakult ja seemned valmisid viki kauntes 3–4 nädalat tavalisest varem. Ka nisu valmis segaviljas tavatult vara, 4 päeva vikist hiljem. Sellistes tingimustes oli taimikul võimalus toitaineid omastada ja orgaanilist ainet sünteesida tunduvalt lühema perioodi jooksul ja sedagi taimekasvuks äärmiselt ekstreemsetes tingimustes. Selle tulemusena jäi segavilja saak madalaks, olles alla 1000 kg ha^{-1}. Kuiv (sademeid kasvuperioodil 150 mm) ja suhteliselt soe oli ka 2002. aasta, mil segavilja saak jäi alla 2000 kg ha^{-1}. Ka sellel aastal valmis vikk segaviljas mitu nädalat tavalisest varem ning nisu vikist 3–4 päeva hiljem. Segavilja saagis kajastub lisaks sademete hulgale ka kahe nimetatud aasta taimede kasvuperioodi keskmisest suhteliselt kõrgem õhutemperatuur. See tingis saakide kiirema valmimise, mistõttu need koristati varakult.

Teistsugune oli viki valmimine keskmise õhutemperatuuriga ja sademetega aastatel, siis valmis vikk nisust hoopis mõni päev hiljem. Andmetest järeldub, et sademete ja segukülvi saagi vaheline seaduspärasus kehtib vaid juhul, kui nisu ja viki–nisu segukülve kasvatatakse teravilja (nisu) järel. Teistsuguste eelviljade puhul see enam ei kehti. Kartuli ja ristiku järel läbiviidud katsete tulemuste lisamine andmete hulka suurendas tunduvalt tulemuste hajuvust ja vähendas determineeritust (determinatsioonikoefitsient R^2 = 0,369). Kartulile järgnemisel on saadud viki–nisu segukülvidest tunduvalt suuremaid kogusaake, isegi üle 4800 kg ha^{-1} (Lauk *et al*., 1999b), sest kartul on parem eelvili kui teravili ja kuna kartulit väetati orgaanilise väetisega, siis seetõttu võis olla tegemist väetise järelmõjuga.

Meie poolt läbi viidud uuringus osutusid odra–herne segukülvide saagid suhteliselt väikesteks, maksimaalselt 2253 kg ha^{-1}, sest väetisi ei antud ja eelviljaks oli teravili ning oder ei suutnud konkureerida hernega (**I**, tabel 1). Jenseni (1996a) poolt läbiviidud uuringutest selgus, et herne–odra segukülvid ületasid stabiilsuse poolest herne puhaskülve, kuid jäid selles osas alla odra puhaskülvile. Odra–herne segukülvidest saadud suurem saak (4600 kg ha^{-1}) Saksamaal viitab soodsale agrofoonile (Hauggaard–Nielsen *et al*., 2001). Töö tulemustest järeldub, et segukülvide produktsioonivõime oleneb sellest, millise teraviljaliigiga kaunvilju koos kasvatada. Tunduvalt suuremat saaki andsid viki–kaera ja herne–kaera segukülvid võrreldes viki–nisu või herne–nisu segudega. Selline seaduspärasus ilmnes sõltumata ilmastiku tingimustest vegetatsiooniperioodil. Näiteks saadi kaeraga enamsaake nii aastatel 2000–2002 kui ka 2003. ja 2004. aastal (**I**, tabel 1; **II** tabel 2; **IV**, tabelid 1, 2). Kaunviljade–kaera segukülvide suurem saak võrreldes kaunviljade–nisu segukülvi saagiga formeerus just kaera arvelt, sest kaunviljade saak segukülvis kaeraga oli madalam kui segukülvis nisuga. Herne–odra segukülvi saak oli teiste segudega võrreldes madalam. Lämmastikväetiseta mullal jäi odra kõrs lühikeseks ja nõrgaks, mistõttu segukülvid lamandusid tugevalt ja saagi koristamine oli raskendatud ning seotud suurte kadudega. Kirjanduse andmetel on kõige konkurentsivõimeliseks teraviljaks kaer, talle järgneb nisu ja kõige tolerantsem kaaskultuuride suhtes on oder (Altieri, 1995; Hauggaard–Nielsen *et al*., 2001; Rauber *et al*., 2001). Meie tulemused on analoogsed.

Antud töö tulemuste põhjal võib öelda, et viki seemnesaak oli aastate lõikes nii puhaskülvis kui ka teraviljadega kooskasvatamisel ebastabiilne. Kui viki saak puhaskülvis oli näiteks 2000. aastal 1376 kg ha^{-1}, siis

2001. aastal oli see peaagu poole kõrgem, 2462 kg ha^{-1}. Võrreldes neid saake näiteks Türgi kuivas kliimas saadud tulemustega, kus viki puhaskülvist saadi 2001 ja 2002. a. keskmisena vaid 650 kg ha^{-1} (Karadag, Buyukburc, 2004), olid meie saagid märkimisväärselt kõrgemad. Eestis varem läbi viidud katsed vikiga on näidanud, et saagid sõltuvad oluliselt ilmastikust ning vikk annab meie tingimustes põuasel aastal segaviljas kasvatatuna tunduvalt väiksema seemnesaagi kui neil aastatel, mil sademete summa vegetatsiooniperioodil on normilähedane või normist mõnevõrra suurem (Rootsi, 1934; Rootsi, 1935; Lühikokkuvõtteid …, 1946; Reimets, 1969). Ka paljud teised teadlased on väitnud, et kaunviljad on eriti tundlikud veepuuduse suhtes (Kalev, Hindoalla, 1990; Guilioni *et al*., 2003; Grain…, 2003). Mullavee defitsiidi tingimustes on kaunviljade kuivainesaagid jäänud kaks korda väiksemaks kui kasvuks soodsatel aastatel (Tjurin *et al*., 1984). Blagoveštšenskoi (1984) andmetel on mullavee küllaldane olemasolu vajalik just kaunviljade generatiivse arengu esimesel poolel. Seemnete valmimine peaks aga toimuma kuivade ilmadega, sest siis ei lähe seemned kaunas kasvama. Kaunviljade suure saagilanguse põhjuseks sademetevaesel vegetatsiooniperioodil võib olla see, et kuivas mullas on takistatud kaunviljade sümbiootiline tegevus mügarbakteritega, mis seovad õhulämmastikku ning on liblikõieliste edukuse oluliseks teguriks. Seega sõltuvad kaunviljade poolt seotud õhulämmastiku kogused oluliselt vegetatsiooniperioodi iseärasustest (Papastylianou, 1999; Peoples *et al*., 2001). Soodsa vegetatsiooniperioodiga aastal võib viki maapealne mass sisaldada üle 100 kg ha^{-1} mügarbakterite poolt seotud õhulämmastikku. Kuivades tingimustes on aga viki maapealses massis fikseeritud õhulämmastikku alla 60 kg ha^{-1} (Mueller, Thorup–Kristensen, 2001).

Antud tööst selgus, et just kaunviljad (vikk, hernes) avaldasid teraviljade (nisu, kaer, oder) saagipotentsiaalile väga tugevat negatiivset mõju. Samade järeldusteni on jõudnud oma töös ka Quiroz ja Mulas (2005). Teraviljade saagilangus oli segus kaunviljadega eriti suur sademeterikka vegetatsiooniperioodiga aastatel (**IV**, tabel 1). Teraviljade üheks saagilanguse põhjuseks oli segude koosseisus tunduvalt väiksemate terade moodustumine (**I**, tabel 1; **II**, tabel 1). Teraviljade omavaheline võrdlus näitas, et kaeral oli 1000 seemne massi vähenemine ja saagilangus segukülvides väiksem kui nisul. Sellest järeldub, et kaer on segus konkurentsivõimelisem kui nisu. Kaunviljade võrdlus näitas, et vikiga kooskasvatamisel oli teraviljade 1000 tera massi vähenemine ja saagilangus suuremad kui need näitajad olid kooskasvatamisel hernega. Määravaks oli siin kindlasti see, et hernes oli vikist mõnevõrra lühema varrega, mistõttu ka väiksema konkurentsivõimega.

Paljude teadlaste poolt on täheldatud teravilja terade proteiinisisalduse tõusu segukülvides kaunviljadega (Lunnan, 1989; Chapko *et al*., 1991; Knudsen *et al*., 2004; Makke, 1997). Meie uurimuses esines samasugune seaduspärasus. Täiendavalt ilmnes, et kooskasvatamisel kaunviljadega vähenesid teraviljade proteiinisaagid pinnaühikult, mis on tingitud teraviljade saagi vähenemisest. Hinnates tulemusi teraviljade proteiinisaakide järgi ja arvestades, seda et 70% teraviljade poolt kasutatud lämmastikust paikneb terades (Loomis, Connor, 1996), võib öelda, et kooskasvatamisel kaunviljadega teraviljade poolt kasutatud lämmastikukogused vähenevad. See võib olla tingitud teravast liikidevahelisest konkurentsist. Konkurents seisneb ilmselt fotosünteetiliselt aktiivse päikesekiirguse kasutamises, kuna vegetatsiooniperioodi teisel poolel, peale teraviljade loomist, oli kaunviljataimede lehtede paigutus selline, et teraviljade alumised kõrrelülid ja lehed olid kaunviljade poolt varjutatud. Veelgi halvem olukord valitses variantides, kus kasutati suuri kaunvilja külvisenorme. Sageli põhjustas see segukülvide lamandumist. Väiksem võimalus kasutada fotosünteetiliselt aktiivset kiirgust oli teraviljadel takistuseks lämmastikuta ekstraktiivainete sünteesil terade formeerumise ja täitumise ajal. Selle tulemusena moodustusidki teraviljadel kooskasvatamisel kaunviljadega tunduvalt väiksemad viljaterad, mis olid aga suurema lämmastikusisaldusega. Kaunviljade negatiivne mõju oli seda suurem, mida paremad olid tingimused nende vegetatiivseks kasvuks ja saagi moodustamiseks. Pikemaajalistes rohumaakatsetes on täheldatud, et liblikõieliste (valge ristik) poolt seotud õhulämmastik vabanes mulda ja seda said kasutada kõrrelised heintaimed teisel ja järgnevatel kasutusaastatel (Hogh–Jensen, Schjoerring, 1997; Jorgensen *et al*., 1999). Herne poolt seotud õhulämmastiku kasutamist odra poolt on täheldatud nõukatsetes (Jensen, 1996b). Antud tulemuste põhjal võib siiski öelda, et kui põllu tingimustes vabanebki segukülvist mulda teatud osa kaunviljade poolt seotud õhulämmastikust, siis teraviljadel ei ole seda võimalik seoses valguse defitsiidiga terava konkurentsi tõttu vegetatsiooniperioodi teisel poolel kasutada.

Proteiinisaagi seisukohalt lähtudes osutusid käesoleva uurimistöö põhjal parimaks nisu–viki segukülvid (kuni 500 kg ha^{-1}) isegi kuivemates tingimustes. Viki–kaera segukülvide proteiinisaak oli mõnevõrra väiksem (kuni 440 kg ha^{-1}; **II**, tabel 2). Proteiinisaaki mõjutas kõige enam kaunvilja külvisenorm. Maksimaalne proteiinisaak saadi viki–teraviljade segukülvides siis kui viki külvisenorm oli 60 seemet m^{-2}. Teraviljade võrdlus näitas, et kaeraterade proteiinisisaldus oli madalam kui nisu terades. Üldistades pikema perioodi andmeid (1994–2004) selgus, et nisu

puhaskülvi proteiinisaak varieerus vahemikus 175–480 kg ha^{-1}. Viki–nisu segukülvid võivad anda sõltuvalt konkreetsest olukorrast 100–500 kg ha^{-1} võrra suuremaid proteiinisaake kui nisu puhaskülvid (**III**, joonis 3). Kõikidel juhtudel oli kaunviljade–teraviljade segukülvide proteiinisaak suurem kui teraviljade puhaskülvides, sealhulgas ka herne–teravilja segudes. Herne–teraviljade segudes saadi suurim proteiinisaak (490 kg ha^{-1}) kolme aasta keskmisena hernesort ‘Kirke’ kooskasvatamisel kaeraga, kusjuures herne külvisenormiks oli 80 seemet m^{-2} (**I**, tabel 3).

Kaunviljade–teraviljade segusid võib kasvatada kõrgema proteiinisisaldusega sööda saamiseks, kuid segukülve võib kasvatada ka kaunviljade seemne paljundamise eesmärgil. Mõningatel juhtudel on vihmastel aastatel herne kasvatamine koos tugikultuuriga ainsaks võimaluseks saada kvaliteetset herneseemet (Kalev, Hindoalla, 1985). Tugikultuur soodustab kaunvilja seemnete ühtlasemat valmimist ja väldib kaunviljade lamandumist (Rosentals, 1970). Kui soovitakse kaunvilju kasvatada seemne saamise eesmärgil koos tugikultuuriga, ei oma segukülvi kogusaak erilist tähtsust. Sellisel juhul on tähtis vaid saavutada kaunvilja võimalikult suur seemnesaak. Kaunviljade seemneks kasvatamisel tuleks antud töö tulemuste põhjal eelistada tugikultuurina nisu, sest avaldab kaunviljadele väiksemat survet ning kaunviljade seemnesaagid kujunevad suuremaks.

6.2. Lämmastikväetise mõju viki–nisu segukülvides

Antud töö tulemused näitasid, et lämmastikväetise mõju oli viki puhaskülvis negatiivne (**V**, tabel 2). Varasemates katsetes samas kasvukohas (1994–1998) sellist negatiivset mõju ei ole täheldatud (Lauk *et al*., 1999b). Viki–nisu segukülvides suurendas lämmastikuga väetamine segukülvi saake, kuid väetise efektiivsus oli väiksem kui nisu puhaskülvides, sest N–väetis mõjus segukülvi komponentide saagile erinevalt. Kuigi lämmastikväetis suurendas segaviljas kasvava nisu saaki, vähenes samal ajal viki saak ning selle tulemusena vähenes viki osatähtsus segavilja saagis oluliselt (**V**, tabel 2). Väetise negatiivse mõju ulatus viki seemnesaagile sõltub viki külvisenormist. Mida väiksem oli viki ja mida suurem nisu osatähtsus seemnesegus, seda suurem oli lämmastikväetise negatiivne mõju viki seemnesaagile segukülvis nisuga. Sademerikastel aastatel ilmnes samasugune tendents. Väiksema viki külvisenormi juures (kuni 60 seemet m^{-2}) oli lämmastikväetise mõju viki seemnesaagile negatiivne. Suurte viki külvisenormide juures (100–120 seemet m^{-2}) oli aga väetise mõju viki saagile positiivne (**IV**, tabel 1). Sama on täheldatud ka meie poolt läbi viidud varasemates uuringutes (Lauk *et al.*, 1999b). Jensen (1996a) on leidnud, et herne–odra segukülvides ei suurenda lämmastikväetis segukülvi saaki, kuid vähendab herne osatähtsust saagis.

Mitmes uurimuses on järeldatud (Jensen, 1986; 1996a; Hauggaard–Nielsen *et al.*, 2001), et kaunviljade–teraviljade segukülvid annavad suuremaid seemnesaake kui teraviljade puhaskülvid. Meie saime katsetes erinevaid tulemusi. 2000. ja 2001. aastate keskmiste põhjal olid nisu saagid puhaskülvis, sõltuvalt väetamisest (N_0, N_{34} ja N_{68}), vahemikus 3370–4009 kg ha^{-1}. Sellistes tingimustes saadi viki–nisu segukülvidest suuremat saaki ainult väetamata mullal ja viki väikese külvisenormi (12 idanevat seemet m^{-2}) juures (**V**, tabel 1). Samas, 2003. ja 2004. aastate keskmisena oli nisu saak väetiseta mullal ja väetamisel (N_{50}) suhteliselt madal (vastavalt 1938 ja 2400 kg ha^{-1}), andsid viki–nisu segukülvid tunduvalt suuremat saaki võrreldes nisu puhaskülvidega (**IV**, tabel 1). Seega sõltub viki–nisu segukülvi sünergiline efekt sellest, millised on tingimused nisu puhaskülvis saagi formeerumiseks. Kui tingimused nisu kasvuks ja arenguks on soodsad, eriti lämmastiktoitumise seisukohast lähtudes, ei tarvitse viki–nisu segukülvidest saada suuremaid saake võrreldes nisu puhaskülvidega. See seaduspärasus kehtib juhul kui viki–nisu segukülve ja nisu puhaskülve kasvatatakse teravilja järel.

Ka ristiku järel kasvatamisel (1998. aastal), kui nisu puhaskülvi saagitase oli 3700 kg ha^{-1} moodustasid viki–nisu segukülvid väiksema saagi kui nisu puhaskülvid (Lauk, Lauk, 1999). Teistsuguseid tulemusi on saadud nisu puhaskülvi ja viki–nisu segukülvide järgnemisel kartulile (Lauk *et al.*, 1999b). Kartulile järgnemisel saadi viki–nisu segukülvidest tunduvalt suuremaid saake võrreldes nisu puhaskülvidega nii väetamata kui ka väetatud mullal (N_{34}) vaatamata sellele, et nisu puhaskülvi saagitase oli kõrge (vastavalt 3904 ja 5082 kg ha^{-1}). Ilmselt on tegemist kartulile antud sõnniku järelmõjuga.

Kirjanduse andmeil annavad kaunviljade–teraviljade segukülvid suuremaid proteiinisaake kui teraviljade puhaskülvid (Hauggaard–Nielsen *et al.*, 2001; Jensen, 1986; 1996a). Kahe katseaasta (2000–2001) keskmisena oli antud töös viki–nisu segukülvi proteiinisaak lämmastikväetiseta mullal maksimaalselt 580 kg ha^{-1} (**V**, tabel 4). Nisu puhaskülvi proteiinisaak jäi aga tunduvalt väiksemaks ja seda isegi juhul kui nisu väetati lämmastikväetisega (N_{68}). Samal katsepõllul varem läbiviidud katsetes on

saadud väetamata mullal kasvatatud viki–nisu segust proteiinisaake üle 600 kg ha^{-1} (Lauk, Jaama, 1995; Lauk *et al.*, 1999a), mis on ligilähedane meie tulemustega. Kui segavili järgnes kartulile olid proteiinisaagid isegi 700–1200 kg ha^{-1} (Leis, 1998). Lämmastikväetise positiivne mõju viki–nisu segukülvi proteiinisaagile oli väiksem kui väetise mõju nisu puhaskülvi proteiinisaagile. See on tingitud sellest, et viki osatähtsus segukülvis lämmastiku mõjul väheneb. Katses oli suurimaks lämmastiku normiks 68 kg ha^{-1}. Sellise normi korral oli nisu puhaskülvi proteiinisaak maksimaalselt 467 kg ha^{-1}. Järelikult on nisu puhaskülvi ja viki–nisu segukülvi proteiinisaagi võrdsustamiseks vaja kasutada nisu puhaskülvis suhteliselt suuri lämmastiku norme. Kindlasti peavad normid olema suuremad kui need olid meie poolt läbiviidud katsetes. Seetõttu võiks kaunviljade–teraviljade segukülve soovitada eriti ökoloogilise maaviljeluse tingimustesse, sest tagavad suhteliselt hea saagi kerge liivsavi lõimisega kahkjal mullal ka neil juhtudel, kui lämmastikväetist ei kasutata. Tavaviljeluse tingimustes aitavad kaunviljade–teraviljade segukülvid kokku hoida lämmastikväetist.

JÄRELDUSED

- Meie hüpotees, et kaunviljade–teraviljade segukülvide sünergiline efekt sõltub looduslikest teguritest ja inimese poolt loodud tingimustest, osutus tõeks. Viki–nisu segukülvide kasvatamisel teravilja järel ilmneb segukülvide sünergiline efekt kui komponentide saagitase puhaskülvis jääb alla 3000 kg ha^{-1}. Sünergilise efekti ilmnemist takistas ebasoodne ilmastik, aga samuti lämmastikuga väetamine (**II**, **III**, **IV**, **V**).
- Tööst järeldub, et kaunviljade–teraviljade segukülvides toimub tugev liikidevaheline konkurents, milles on agressiivsemaks pooleks kaunvili. Kaunviljade negatiivne mõju teraviljade saagile sõltus kaunviljade külvisenormist ja see kasvas koos külvisenormi suurenemisega. Teraviljade saagilanguse üheks põhjuseks segukülvides oli väiksemate terade moodustumine, mis väljendus väiksemate 1000 tera massidena. See oli negatiivses seoses kaunviljade külvisenormi suurenemisega (**I**; **II**, **IV**).
- Kaunviljade seemnesaagid olid segus nisusordiga 'Tjalve' suuremad kui segus kaerasordiga 'Jaak'. Seega on nisu segus väiksema konkurentsivõimega kui kaer, mistõttu tuleks kaunviljade kasvatamisel seemneks eelistada tugikultuuriks nisu. Lämmastikuga väetamine suurendas nisu konkurentsivõimet viki–nisu segus (**I**, **II**, **IV**).
- Kaunvilja väikesel külvisenormil (20 idanevat seemet m^{-2}) oli hernesordi 'Kirke' saak ligikaudu 2 korda väiksem kui vikisordi 'Carolina' saak samasuguse külvisenormi juures. See näitab, et teraviljade konkurentsivõime on herne suhtes suurem kui viki suhtes ning seda just kaunviljade väiksemate külvisenormide puhul (**IV**).
- Viki puhaskülvi ja viki–teravilja segukülvide saagid sõltusid oluliselt kasvuaegsetest ilmastikutingimustest. Viki–teravilja saak ei erinenud kuivadel suvedel oluliselt nisu puhaskülvi saagist, kuna kuivus ei soosinud viki arengut. Sademeterikkail aastail andis segavili tuntava enamsaagi vastavate teraviljade puhaskülvidega võrreldes. Saak sõltus oluliselt viki külvisenormist ning suurim saak moodustus siis kui viki külvisenorm oli 40–50 idanevat seemet m^{-2} (**II**, **III**, **IV**).
- Uudsena ilmes, et viki–nisu segukülvidel on eelis saagi seisukohalt lähtudes nisu puhaskülvide ees juhul, kui nisu puhaskülvi saagitase jäi vahemikku 1500–3000 kg ha^{-1}. Viki–nisu segukülvid tagavad ligikaudu 3000 kilogrammise hektarisaagi kui sademete hulk on kasvuperioodil 300±50mm (**III**).

- Herne–teravilja segukülvide saagid sõltusid samuti ilmastikutingimustest. Kui kuivematel aastatel saadi segukülvidest kuni 225 kg enamsaaki võrreldes teraviljade puhaskülvidega, siis sademeterikkamatel aastatel oli segukülvide saak puhaskülvi saagist suurem kuni 690 kg ha^{-1}. Ka herne puhul oli määravaks külvisenorm ning maksimaalne enamsaak saavutati siis kui herne külvisenorm oli 70–80 idanevat seemet m^{-2} (**I**; **IV**).
- Töö põhjal tõestati, et viki–kaera ja herne–kaera segukülvid annavad suuremaid seemnesaake kui viki–nisu ja herne–nisu segukülvid, kusjuures suurem saak saadi kaera saagi arvel. Seega, kui kaunviljade–teraviljade segukülvide kasvatamisel on eesmärgiks maksimaalne produktsioon, siis tuleb eelistada tugikultuurina kaera (**I**; **II**, **IV**).
- Madalaim oli segukülvi saak kombinatsioonis hernes+oder 'Elo'. Herne–odra segukülvide osas tuleb jätkata uurimistööd, et leida sobivaim odrasort kooskasvatamiseks hernega 'Kirke'. Katses olnud oder 'Elo' ei sobinud segusse eelkõige tema lühikese kõrre ja väikese konkurentsivõime tõttu (**I**).
- Kuigi proteiinisisaldus teravilja terades kaunvilja külvisenormi suurenedes suurenes, siis teraviljade lämmastiktoitumise tingimused terade moodustumise ajal halvenesid, mistõttu terasaakidega eemaldatavad lämmastikukogused pinnaühikult olid maksimaalselt 2–3 korda väiksemad kui puhaskülvides, mis tulenes teraviljade terasaagi langusest kooskasvatamisel kaunviljadega (**I**; **II**, **IV**).
- Pikaajaliste katsete tulemusi üldistades saame järeldada, et normaalse veevarustuse korral tagavad viki–nisu segukülvid 600–700 kilogrammilise proteiinisaagi hektarilt, samal ajal kui nisu puhaskülvi proteiinisaagid samades tingimustes olid kuni kolm korda väiksemad. See kehtib vaid tingimustes, kus segukülvid järgnevad teraviljale (**III**).
- Lämmastikuga väetamisel (N_{34}, N_{68}) olenes väetise efektiivsus ning saak seemnete vahekorrast segus. Viki–nisu segukülvide väetamisel oli lämmastikväetise efektiivsus tunduvalt väiksem kui nisu puhaskülvis. Segukülvide erinevate komponentide saagile mõjus väetamine erinevalt – nisule positiivselt, vikile negatiivselt. Lämmastikväetise negatiivne mõju viki seemnesaagile suurenes seoses viki osatähtsuse vähenemisega seemnesegus. Seega viki väiksema osatähtsuse juures segus on nisu suurema konkurentsivõimega kui vikk ja lämmastikväetise kasutamisel suurendame eelkõige nisu konkurensivõimet (**V**).

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KOKKUVÕTE

Eestis kasvatatakse segaviljana koos tera– ja kaunvilju peamiselt terasaagi saamiseks. Segaviljade kasvatamisel püütakse matkida looduslikke taimekooslusi, milliste produktiivsus on sageli suurem kui ühe liigiga taimikul. Kuna segavilja komponentidel on mullapealsete ja –siseste taimeorganite asetus, aga samuti taimede bioloogilised vajadused erinevad, siis kasutavad segukülvid kasvukeskkonna võimalusi paremini kui üheliigilised külvid.

Käesolevas uurimuses võeti kaunviljadest segavilja komponentideks vikk ja hernes. Mõlemad liblikõielised kuuluvad väärtuslike valgurikaste söödataimede hulka. Nad on saagikad, pika perioodi jooksul söödana kasutatavad ja väärtusliku keemilise koostisega. Vikki ja hernest kasvatatakse koos teiste kõrrelistega nii haljassöödaks, haljasväetiseks, seemneks, siloks, heinaks ja vahel karjatamiseks. Nimetatud kaunviljadele sobivad meie tingimustes tugikultuurideks teraviljadest nisu, kaer ja oder.

Käeoleva uurimistöö hüpoteesiks oli, et kaunviljade–teraviljade segukülvide sünergiline efekt võib oluliselt sõltuda nii looduslikest teguritest (ilmastik) kui ka inimese poolt loodud tingimustest (erinevad tugikultuurid, külvitihedus, seemnesegu vahekorrad, lämmastikuga väetamine).

- Uurimistöö käigus sooviti selgitada, mil määral ja kuidas mõjutab segukomponentide (kaunvili–teravili) omavaheline konkurents nende saagipotentsiaali.
- Leida segukülvide jaoks optimaalne külvisenorm ja komponentide õige vahekord ning sobiv tugikultuur kaunviljadele nende kasvatamisel seemneks või söödaks.
- Hinnata kaunviljade–teraviljade segukülvide väärtust, kasutades näitajatena seemnesaaki, proteiinisaaki ning saagi proteiinisisaldust ning võrrelda neid teraviljade puhaskülvide näitajatega.
- Selgitada lämmastikväetise mõju viki–nisu segukülvides komponentide erineva vahekorra juures ning võrrelda seda teraviljade puhaskülvidega.
- Hinnata meteoroloogiliste tingimuste mõju segaviljade saakidele.

Meie hüpotees, et kaunviljade–teraviljade segukülvide sünergiline efekt sõltub looduslikest teguritest ja inimese poolt loodud tingimustest, osutus tõeks. Viki–nisu segukülvide kasvatamisel teravilja järel segukülvide sünergiline efekt ilmneb kui komponentide saagitase puhaskülvis jääb alla

3000 kg ha^{-1}. Sünergilise efekti ilmnemist takistas ebasoodne ilmastik, aga samuti lämmastikuga väetamine.

Segaviljaga läbi viidud katsete tulemustest selgus, et kaunviljade–teraviljade segukülvides toimib tugev liikidevaheline konkurents, kusjuures agressiivsemaks pooleks oli kaunvili. Kaunviljade seemnesaagid olid segus nisusordiga 'Tjalve' suuremad kui segus kaerasordiga 'Jaak'. Seega osutus kaer nisust konkurentsivõimelisemaks, mistõttu tuleks kaunviljade kasvatamisel seemneks eelistada tugikultuurina nisu. Segukülvides väheneb kaunvilja külvisenormi suurenedes teravilja terasaak, 1000 seemne mass ja proteiinisaagid pinnaühikult.

Saagikuse seisukohalt lähtudes ei omanud 2000.–2002. aasta keskmisena viki–teravilja segukülvid teraviljale järgnemisel olulist eelist teraviljade puhaskülvi ees, mis oli tingitud teraviljade suhteliselt kõrgest saagikusest puhaskülvis ja põuast 2002. aastal. Küll aga saadi suuremaid saake (2882–3814 kg ha^{-1}) 2003. ja 2004. aasta keskmisena viki 'Carolina' külvisenormil 40–50 idanevat seemet m^{-2}. Selgus, et viki–nisu segukülvid kaotasid saagis eelise teraviljale järgnemisel juhul, kui nisu puhaskülvi saagitase ületas 3000 kg ha^{-1}. Tingimustes, kus nisu puhaskülvi saagitase jäi vahemikku 1500–3000 kg ha^{-1}, tagasid viki–nisu segukülvid kasvuperioodi sademete hulga 300±50 mm juures saagi ca 3000 kg ha^{-1}.

2000.–2002. aasta keskmisena saadi maksimaalne saak herne–teravilja (nisu, kaer) segukülvidest (2776–3380 kg ha^{-1}) herne 'Kirke' külvisenormil 40–60 idanevat seemet m^{-2}. Kahe järgneva sademeterikka aasta (2003–2004) keskmisena saadi herne–teravilja (nisu, kaer) segukülvis maksimaalne saak (2860–3500 kg ha^{-1}) herne külvisenormil 70–80 idanevat seemet m^{-2}. Madalaim oli segukülvi saak kombinatsioonis hernes+oder 'Elo'. Kaunvilja väikesel külvisenormil (20 idanevat seemet m^{-2}) oli herne saak ligikaudu 2 korda väiksem kui viki saak samasuguse külvisenormi juures.

Kaunviljade–teraviljade segukülvid omavad eelist teraviljade puhaskülvides ees proteiinisaagi seisukohalt. Üldistus pikema perioodi kohta näitab, et normaalse veevarustuse korral tagavad viki–nisu segukülvid teraviljale järgnemisel 600–700 kilogrammilise proteiinisaagi hektarilt (nisu puhaskülvi proteiinisaagid samades tingimustes olid vahemikus 175–480 kg ha^{1}).

Lämmastikväetise efektiivsus nisu puhaskülvi väetamisel sõltus oluliselt meteoroloogilistest tingimustest kasvuperioodil. 2000.–2001. aasta keskmisena oli lämmastikväetise (N_{68}) keskmine efektiivsus nisu puhaskülvis 9,4 kg teri 1 kg lämmastiku kohta. Lämmastikuga väetamisel (N_{34}, N_{68}) saadi maksimaalne segukülvi saak juhul, kui vikki võeti seemnesegusse 12 ja nisu 438 idanevat seemet ruutmeetrile. Viki–nisu segukülvide väetamisel oli lämmastikväetise efektiivsus tunduvalt väiksem kui nisu puhaskülvis, kuna segukülvide erinevate komponentide saagile mõjus väetamine erinevalt – nisule positiivselt, vikile negatiivselt. Kuna proteiinisaakide osas mõjus väetamine samuti nisule positiivselt ja vikile negatiivselt siis oli väetise mõju segukülvi proteiinisaagile suhteliselt tagasihoidlik ja väiksema lämmastikväetise normi puhul mitteusutav. Kui lähtuda proteiinisaakidest, siis saab viki–nisu segukülve kasvatada ilma lämmastikväetiseta.

Kokkuvõtvalt võib kaunviljade–teraviljade segukülve soovitada ökoloogilise maaviljeluse tingimustesse, sest nad tagavad suhteliselt hea saagi kerge liivsavi lõimisega kahkjal mullal ka neil juhtudel, kui lämmastikväetist ei kasutata. Tavaviljeluse tingimustes aitavad kaunviljade–teraviljade segukülvid kokku hoida lämmastikväetist.

SUMMARY

In Estonia cereals and legumes are grown together for the purpose of gaining grain yield. With mixed crops, it is tried to imitate natural compositions, whose productivity is often higher than that of one single species. As components of mixed crops are differently located in abovesoil and insoil plant organs and have different biological needs, mixed crops make better use of the possibilities offered by their growth environment than single species sown.

This research involved vetch and pea as the legume components of mixed crops. Both the papilionaceous plants belong to valuable feedplants rich in protein. They are productive, can be used as feed for a long period and have a valuable chemical content. Vetch and pea are grown together with other grasses for green fodder, green fertiliser, seed, silage, and hay. In our conditions, support cultures suitable for the legumes selected are wheat, oats, and barley.

The hypothesis of this research was that the synergic effect of legume–cereal mixed crops may considerably depend on both natural factors (rainfall) and conditions created by humans (different support cultures, sowing density, the ratio in the seed mix, fertilisation with nitrogen).

The research had the following main objectives:

- To establish how competition between legumes and cereals affects the yield potential of different species.
- To find the optimum sowing rate and the right ratio of components for mixed crops, as well as to determine the most suitable support crop for legumes when growing them for seed and fodder.
- To estimate the value of legume–cereal mixed crops for the seed yield, protein yield and the protein content of the yield.
- To find out the extent of the effect of nitrogen fertiliser in vetch–wheat mixed crops at different ratios, compared with pure cereal crops.
- To assess the effect of meteorological conditions on yields of mixed crops.

Thus the hypothes that the synergic effect of legume–cereal mixed crops may considerably depend on both natural factors (rainfall) and conditions created by humans (different support cultures, sowing density, the ratio in the seed mix, fertilisation with nitrogen) was confirmed. The synergic effect of growing vetch–wheat mixed stands after cereals appears as the yield level of single crops below 3000 kg ha^{-1}.

The results of experiments carried out with mixed crops revealed that, in legume–cereal mixed crops, there was strong interspecies competition whereas the more aggressive party were the legumes. Of cereals, oats cv. Jaak proved somewhat more competitive than wheat cv. Tjalve. When growing vetch and pea varieties for seed together with a support culture, wheat should be the cereal used. In mixed crops, the seed yield of cereals, 1000–seed weight and protein yield from a surface unit were decreased when the sowing rate of legumes was increased.

From the position of the yield, vetch–cereal mixed crops, when they followed cereals, had, as the average of 2000–2002, no considerable advantage over pure wheat crops, which was caused by the relatively high yield of wheat in the pure crops and the draught in 2002. Larger yields (2882–3814 kg ha^{-1}) were gained as the average of 2003 and 2004 at a sowing rate of 40–50 germinating vetch cv. Carolina seeds m^{-2}. It appeared that the vetch–wheat mixed crops lost their yield advantage, when they followed cereals, in case the yield level of pure wheat crops exceeded 3000 kg ha^{-1}. In conditions when the yield level of pure wheat crops was between 1500–3000 kg ha^{-1}, vetch–wheat mixed crops ensured a yield of ca 3000 kg ha^{-1} at 300±50mm precipitation in the growth period.

As the average of 2000–2002, the maximum yield was gained from pea–cereals (wheat, oats) mixed crops (2776–3380 kg ha^{-1}) at a sowing rate of 40–60 germinating pea cv. Kirke seeds m^{-2}. As the average of the two next years (2003–2004) of much precipitation, pea–cereals (wheat, oats) mixed crops produced the maximum yield (2860–3500 kg ha^{-1}) at a sowing rate of 70–80 germinating pea seeds m^{-2}. The lowest total yield was in combination pea+barley cv. Elo. At the lowest legumes seeds density (20 germinating seeds per 1m^{-2}) the yield of pea was two times lower than the yield of vetch at the same seed density.

Legume–cereal mixed crops have an advantage over pure cereal crops with their protein yield. Generalisation of a longer period shows that, with normal water supply, vetch–wheat mixed crops following a cereal ensure 600–700 kg protein yield per hectare (the protein yields of pure wheat crops in the same conditions were between 175–480 kg ha^{1}).

The effectiveness of nitrogen fertiliser in fertilisation of pure crops depended considerably on the meteorological conditions in the growth period. As the average of 2000–2001, the average effectiveness of N fertiliser (N_{68}) in pure crops was 9.4 kg seeds per 1 kg of nitrogen. In fertilisation with nitrogen (N_{34}, N_{68}), a maximum mixed crop yield was gained in case 12 germinating seeds of vetch and 438 germinating seeds of wheat were added to the seed mix. With fertilisation of vetch–wheat mixed crops, the effectiveness of nitrogen fertiliser was considerably lesser than in pure wheat crops as the fertilisation affected the yields of different components differently – wheat positively and vetch negatively. As, with protein yields, fertilisation also affected wheat positively and vetch negatively, the effect of the fertiliser on the protein yield of mixed crops was relatively modest and not plausible at a smaller N fertiliser norm. With respect to protein yields, vetch–wheat mixed crops can be grown without N fertiliser.

Legume–cereal mixed crops are ideally suited in conditions of ecological agriculture as they ensure a considerably good yield also in cases no N fertiliser is used. In conditions of traditional farming, legume–cereal mixed crops help save N fertilisers.

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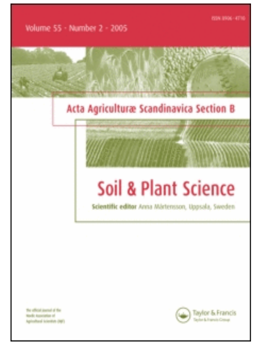

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Pea-oat intercrops are superior to pea-wheat and pea-barley intercrops

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ORIGINAL ARTICLE

Pea-oat intercrops are superior to pea-wheat and pea-barley intercrops

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Abstract

A three-year field experiment was conducted in Estonia to determine which combinations of pea (*Pisum sativum* L.) and wheat (*Triticum aestivum* L.), oats (*Avena sativa* L.) and barley (*Hordeum distichon* L.) were most suitable for mixed cultivation and the effect of pea on the yield potential of cereals. The inclusion of pea in cereal seeds and the increasing of its seed density led to substantial decreases in the grain yields of the cereal component. The reason for these decreases was the formation of smaller grains in cereals when intercropped with pea. The inclusion of pea in a cereal crop and the increasing of its seed density led to substantial increases in the protein content of the cereal grains. In barley and oats the increases in grain protein content were the lowest of the three cereals. At the same time, the maximum protein yield per area unit in cereals was obtained from plots of pure crops. In a mix with pea, the amounts of nitrogen consumed by cereals decreased and the protein yield of cereals per area unit were reduced in intercrops. Pea-cereal mixes had an advantage over cereal sole crops with regard to protein yield, due to the pea component. Pea-cereal mixes are particularly suitable for the conditions of organic farming, and should be recommended to farmers, as they ensure a relatively good harvest and high protein yield on soil without nitrogen fertilizers. In conclusion, the study showed that, of the three combinations, pea-oat mixed intercrops gave the highest yield of grain and protein yields.

Keywords: *Cereals, density, grain, intercrops, mixed, Pisum sativum L., protein, seed, yield.*

Introduction

Lodging, due to heavy and/or prolonged precipitation in July and August, is the main hazard affecting the growth, harvest and yield of pea as a sole/pure crop in Estonia. Furthermore, pure pea crops are more vulnerable to weed infestation than pea-cereal mixed crops (Mohler & Liebman, 1987; Liebman & Dyck, 1993; Rauber et al., 2001; Talgre et al., 2005; Hauggaard-Nielsen et al., 2006). Intercropping pea with cereals reduces the risk of nitrogen (N) leaching (af Geijersstam & Mårtensson, 2006). For these reasons pea should be grown in a mix with a support crop. Suitable support crops are cereals: spring wheat, barley and oats and Cruciferae; white mustard and spring oilseed rape (Banik et al., 2000; Rauber et al., 2001; Lauk & Lauk, 2005).

When cereal-pea mixes are grown in the field, attempts are made to imitate natural plant communities. As the location of above- and intra-ground plant organs and also the biological needs of components of intercrops are to some extent different, intercrops may use plant growth resources better than pure crops (Hauggaard-Nielsen et al., 2001a, 2003, 2006). Legumes cover most of their nitrogen requirement from air nitrogen. Pea varieties, on average, accumulate 164 kg nitrogen ha^{-1} per annum, over half of which (65%) has been obtained through fixation of air nitrogen (Corre-Hellou & Crozat, 2005). Competition with the cereal in an intercrop may to some extent cause the pea's accumulation of nitrogen (Jensen, 1996; Hauggaard-Nielsen et al., 2003).

Legume-grain intercrops have produced higher seed and protein yields than pure grain crops (Jensen, 1996; Hauggaard-Nielsen et al., 2001b; Lauk & Lauk, 2005). Furthermore, legume-cereal mixed crops may provide yield advantages and create yield stability over time compared with pure stands of either legumes or cereals (Willey, 1979; Ofori & Stern, 1987). Hauggaard-Nielsen et al. (2006) counter this argument, stating that in some instances

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barley-pea mixed crops had no significant advantage over yields of pure crops of the individual components. The advantage of legume-cereal mixed crops compared with pure cereal crops decreases substantially with use of nitrogen fertilizers (Jensen, 1996; Lauk & Leis, 1997). Nitrogen fertilizers cause a decrease in the proportion of legumes in the grain yield of legume-cereal mixed crops (Jensen, 1996; Lauk & Lauk, 2004). Legume-grain intercrops may lose their advantage over pure cereal crops when conditions for yield formation of pure cereal crops are favourable and the grain yield level of pure cereal crops is high (van den Berg, 1968; Ofori & Stern 1987; Lauk & Lauk, 2006).

In general, the addition of legumes into the crop rotation is considered a pre-condition for improving the general productivity of the rotation (Yau et al., 2003). A good pre-crop for barley, for example, is vetch. Barley's nitrogen accumulation and yield both increased considerably after vetch compared with after grain (Papastylianou, 1990, 2004; Danso & Papastylianou, 1992).

This research had two aims. The first was to study the interactions of the paired components of three mixed intercrops when grown without the use of nitrogen fertilizer. The common component of the intercrops was pea (*Pisum sativum* L.); the other components were wheat (*Triticum aestivum* L.), oats (*Avena sativa* L.) and barley (*Hordeum distichon* L.). The second aim was to analyse and evaluate the aggregate and protein yields for each of these three mixed intercrop combinations to determine the most suitable combination for the prevailing climatic conditions.

Material and methods

The field experiment was conducted over a three-year period 2000–2002 at the Plant Biology experimental station of the Department of Field Crop Husbandry (58°23′N, 26°44′E) of the Estonian University of Life Sciences (EMU). Estonia is located beside the Baltic Sea and sufficiently close to the north-eastern waters of the Atlantic Ocean for significant influence and consequently Estonia's climate is very changeable. The springs are chilly, the summers are often relatively short and cool and the autumns generally long.

The trial series method was used for the field research, as only one replication was needed for the experiment. The data were processed and regression analysis used to calculate the trial error (Lauk & Lauk, 2000; Lauk et al., 2004). There were three trial series: pea with long straw and normal leaves (*Pisum sativum* L. cv. Kirke) was grown in a mix with spring wheat (*Triticum aestivum* L. cv. Tjalve); in the second series pea was grown in a mix with oats (*Avena sativa* L. cv. Jaak) and in the third series pea was grown in a mix with barley (*Hordeum distichon* L. cv. Elo). The size of each trial plot was 10 m^2.

The seed density of the cereals, 250 germinating seeds per m^{-2}, was identical in all the variants of the series. The research programme required that the density of germinating pea seed (henceforth – the sowing rate) vary from 0 to 120 seeds m^{-2}, at 11 increments of 12 seeds m^{-2}. The method enabled the use of single replications of all the variants in the trial series as the regression method can calculate experimental error even in the case of one replication (Little & Hills, 1972; Mead et al., 1993). There were, however, double replications for the series of untreated variant (i.e. the pure stands of cereals); double control figures for a single series make it easier to define the initial point of regression (Lauk & Lauk, 2000).

The field trials were performed on a pseudopodzolic, moderately moist soil having a slightly sandy-clayey texture. The soil properties were as follows: pH_{KCl} of the ploughed layer was 4.9–6.1, organic matter content 2.3–3.2%, and the available phosphorus and potassium contents (determined using the AL method) were 76–174 mg kg^{-1} and 109–204 mg kg^{-1}, respectively. The preceding crop was spring wheat, and fertilizers were not used in the trial years. The seeds of pea and cereals in the mixed intercrop variants were sown into the same row using a special plot drill. Harvesting occurred between 6 and 22 August each year. The yields of the separate components and the aggregate yield of each intercrop were recorded. The moisture content of the yields was calculated at 14%, and the 1000-seed weight and crude protein content were determined for each variant. The yields of crude protein were calculated on the basis of desiccated yield and crude protein content in the dry components.

The overall weather in the first two years of the programme, but crucially the precipitation of 330mm in 2000 and 285mm in 2001, provided good crop growing conditions. Growing conditions were substantially less suitable in 2002, with an average air temperature higher than usual and total precipitation in the growth period being just 147 mm, approximately half the usual amount.

Regression analysis ($y = a + bx + cx^2$) was used to process the average data of the experimental years for each of the series. The independent variable was germinating pea seed density per square metre, and the dependent variables were, respectively: the yield and the protein yield (kg ha^{-1}), the cereal 1000-seed weight (g) and the cereal grain protein content (% in dry matter).

Standard errors (E.S.) and confidence limits ($CL_{0.05}$ – level of statistical significance $p = 0.05$) were calculated using the relevant methodology (Lauk & Lauk, 2000). The reliability of the correlations in the trial series were evaluated using the control values of the correlation coefficients (R), which were taken from the corresponding tables based on the number of the degrees of freedom (df = 12–3) (Little & Hills, 1972). All the numerical values given in the tables were calculated on the basis of the regression equations obtained from regression analysis. To avoid excessive numbers, results have been calculated for the sowing rates 0, 20, 40, 60, 80, 100 and 120 pea seeds m^{-2}.

Results

The data presented in the Table I reveal that, in soil without nitrogen fertilizer, the highest cereal yields were obtained from pure stands. The maximum cereal yield, as an average of the three years, was obtained from the pure stand of oats, 3155 kg ha^{-1}. The yields of wheat and barley under identical circumstances were smaller by 604 kg ha^{-1} and 937 kg ha^{-1}, respectively (level of statistical significance: $p < 0.05$). The inclusion of pea seed in cereal seeds and the regular increment of germinating pea seed density led to substantial decreases in all the cereal yields. The overall decrease in oat grain yields in response to the increased germinating pea seed densities was the smallest of the three cereal species (1159 kg ha^{-1}); accordingly, oats may be considered somewhat more competitive than barley and wheat in a mix with pea. The correlations between the grain yields of the cereal component and germinating pea seed densities were very strong and reliable (R = 0.965–0.993; $p < 0.001$). The maximum total yield, as an average of the three years (slightly over 3380 kg ha^{-1}), was obtained from oat-pea mixes at germinating pea seed densities of 40–60 m^{-2}. The yield of the mixed intercrops was 233 kg ha^{-1} higher than the monoculture of the sole crops. The maximum yield of the wheat-pea mixes (2776 kg ha^{-1}) was obtained at the germinating pea seed density of 40 m^{-2}. The yield was 225 kg ha^{-1} higher than the sole crop of wheat. The yield of a barley-pea mix at germinating pea seed densities of 40–60 m^{-2} was practically the same as that of barley sole crops. The correlations between germinating pea seed density and the intercrops' yields as an average of the three years were strong and reliable for wheat-pea and barley-pea mixes (R = 0.679–0.716; $p < 0.05$) and weak and unreliable for oats-pea mixes (R = 0.526; $p > 0.05$). At all the germinating pea seed densities, the highest yields were produced by oat-pea intercrops. The differences in yield compared to wheat-pea mixes ranged between 580 and 700 kg ha^{-1} ($p < 0.05$), depending on the germinating pea seed density. The higher yield of oat-pea mixes was attributable to oats as a less demanding crop. The yields of barley-pea mixes were considerably lower than those of oat-pea and wheat-pea mixes.

The inclusion of germinating pea seeds in cereal seeds and the regular increment of the germinating pea seed density led to considerable decreases in the cereal 1000-seed weights (R = 0.847–0.984; $p < 0.001$), which was one of the reasons for the reduced cereal yields. The data in Table II (averages for the three years) indicate that the greatest decreases in 1000-seed weight occurred in barley – up to 6.6 g, whereas the figures for wheat and oats under identical circumstances were up to 2.8 g and 1.7 g, respectively. Oat was somewhat more competitive with pea, and therefore the reduction in the 1000-seed weight (and in the yield) attributable to increased germinating pea seed density was not as great in oat as it was in wheat and barley. The average grain protein content, as a percentage in dry

Table I. The formation of seed yields in cereals and seed yields of pea-cereal mixes, as an average for the three years, depending on the pea sowing rate.

	Yield (kg ha^{-1})					
Sowing rate of pea, seeds m^{-2}	Wheat	Wheat+pea mixes	Oats	Oats+pea mixes	Barley	Barley+pea mixes
0	2551	–	3155	–	2218	–
20	2143	2751	2800	3332	1822	2253
40	1802	2776	2510	3382	1507	2209
60	1529	2759	2285	3388	1273	2146
80	1322	2699	2124	3353	1121	2065
100	1182	2597	2028	3275	1051	1965
120	1109	2453	1996	3154	1061	1847
S.E	16.4	29.6	32.7	33.8	29.5	39.9
$CL_{0.05}$	37	67	74	77	67	91
R	0.993	0.679	0.965	0.526	0.973	0.716

Table II. The formation of cereal 1000-seed weights and protein contents in grains, as an average for the three years, depending on the pea sowing rate.

	1000-seed weight (g)			Protein content of grains (%)		
Sowing rate of pea, seeds m^{-2}	Wheat	Oats	Barley	Wheat	Oats	Barley
0	36.4	35.3	39.0	14.1	11.9	12.0
20	35.6	35.1	37.9	14.5	12.2	12.1
40	34.9	34.9	36.7	14.9	12.4	12.3
60	34.3	34.6	35.6	15.3	12.6	12.5
80	33.9	34.3	34.5	15.8	12.8	12.8
100	33.7	33.9	33.4	16.3	13.0	13.2
120	33.6	33.6	32.4	16.7	13.1	13.7
S.E	0.09	0.10	0.11	0.13	0.03	0.10
$CL_{0.05}$	0.2	0.3	0.3	0.3	0.1	0.2
R	0.956	0.847	0.984	0.956	0.970	0.974

matter of the pure cereal stands, was 14.1% for wheat, 11.9% for oats and 12% for barley (Table II). The increments of germinating pea seed densities led to increased grain protein content in wheat, oats and barley. The correlations between germinating pea seed density and cereal grain protein content were very strong and reliable (R = 0.956–0.974; $p < 0.001$). The increases in protein content were the greatest in wheat grain, up to 2.6%, whereas the smallest was in oat grain, up to 1.2%. Pea protein content averaged 24.2% for the three years and for all the trial intercrop variants.

The pure stands of cereals produced the highest cereal protein yields per area unit (Table III). The mixing of germinating pea seeds with cereal seeds and the regular increment of the pea seed density had a very strong and reliable effect on the protein yields of the cereal components in all the trial cases (R = 0.952–0.984; $p < 0.001$). Nevertheless, the overall effect of pea on cereal protein yield was negative. The greatest decreases occurred in pea-wheat mixes at up to 168 kg ha^{-1} on average for the three years. Oat, as both a component of oat-pea intercrop and as a sole crop, produced the greatest protein yields. The protein yield of oat, depending on the germinating pea seed density, was 11–80 kg ha^{-1} greater than that of wheat. Barley produced the smallest protein yields both in each trial year and on average for the three years.

The pea-cereal mixes, by contrast, proved effective in terms of protein yield of the combined components up to a certain point. The inclusion of pea in cereal seeds and the increasing of its seed density led to substantial increases in the protein yields of the mixed intercrops (R = 0.804–0.967; $p < 0.01$ and $p < 0.001$). Increments of germinating pea seed density up to 80 m^{-2} caused an increase, the level depending on the combination, in the pea-cereal intercrops' protein yields. Further increases, beyond 80 m^{-2} in germinating pea seed density, led to reductions in the protein yield. Oat-pea mixes, at all germinating pea seed densities, produced the highest protein yields with the maximum of 490 kg ha^{-1} at 80 m^{-2}. The protein yield was 168 kg ha^{-1} higher than that of sole oat crop. The maximum protein yield of the wheat-pea intercrop crop was marginally lower at 453 kg ha^{-1} and for barley-pea was considerably lower at 316 kg ha^{-1}.

Table III. The protein yields per area unit of cereal grains and pea-cereal mixes, as an average for the three years, depending on the pea sowing rate.

	Protein yield (kg ha^{-1})					
Sowing rate of pea, seeds m^{-2}	Wheat	Wheat+pea mixes	Oats	Oats+pea mixes	Barley	Barley+pea mixes
0	311	–	322	–	227	–
20	263	390	291	402	188	277
40	223	426	266	448	157	303
60	191	448	247	477	135	316
80	167	453	233	490	121	316
100	151	444	225	486	115	304
120	143	419	223	465	118	279
S.E	2.29	5.42	3.36	4.12	3.36	5.81
$CL_{0.05}$	5.2	12.2	7.6	9.3	7.6	13.2
R	0.984	0.908	0.952	0.804	0.962	0.967

Discussion

We presumed, at the start of the study that pea-cereal intercrops produce to some extent a higher yield on soil without N-fertilizer than pure grain crops, and that one of the three intercrop combinations would be more productive. Wheat-pea and oat-pea intercrops proved more productive than pure crops of wheat and oats. The productive differences, however, between the intercrops and pure crops proved smaller than expected. The highest grain yield was obtained when pea was grown together with oat, where the higher yield of the intercrop is due to the oats component. Banik et al. (2000) established that growing mixed crops reduces the yield of the components compared to the yields of their pure crops. Cereals in pea-mix intercrops can be strong competitors to the pea, which explains why the pea yield may be much lower than pea pure crops (Hauggaard-Nielsen et al., 2001a; Andersen et al., 2004). Short-strawed pea cultivars are, therefore, not suitable for growing with oat as an intercrop (Rauber et al., 2001). In our research a long-strawed pea cultivar with normal leaves (*Pisum sativum* L. cv. Kirke) was grown as an intercrop with the three spring cereals and competed intensely with them, causing a grain yield decrease of over 1000 kg ha^{-1} (with maximum sowing rate of pea) compared to their pure crops. The strong negative effect of pea on grain yield appeared even at considerably low sowing rates of pea (Table I).

Several studies have revealed that intercropping cereals with pea, and increasing the sowing rate of pea, enhances the nitrogen concentration in the cereal grain (Lunnan, 1989; Makke, 1997; af Geijersstam & Mårtensson, 2006; Hauggaard-Nielsen et al., 2006). Knudsen et al. (2004) suggest that interspecies competition causes the increase of N concentration in barley grains. When the dominant species in intercrops are legumes there is severe competition for plant growth factors, but nitrogen is not one of them. The pressure of pea on barley is revealed in late growth stages for, as Hauggaard-Nielsen et al. (2006) argue, there is competition for the use of light. In our research, the N concentration in grain increased in all the cereal-pea mixed intercrops and the sowing rates of pea were increased (Table II). The results of the research lead to the conclusion that interspecies competition and the pressure of pea on cereals cause the increase in nitrogen concentration. The competition revolves around the consumption of photosynthetically active solar radiation. The placement of leaves of long-strawed pea (*Pisum sativum* L. cv. Kirke) in the second half of the vegetation period, following the formation of grains in the cereal, is such that they keep the lower stalk segments and leaves of the cereals in their shade. The smaller opportunities for cereals to consume photosynthetically active radiation hinders non-nitrogenous synthesis of extractive substances in cereals during the period of grain formation and filling. The result is that cereals intercropped with pea develop considerably smaller grains (leading to two outcomes – substantial reductions in the 1000-seed weight and lower yields; see Tables I and II), in which the proportion of nitrogen compounds is high (leading to a further outcome – considerably higher protein content in the cereal grains; see Table II). As 70% of the nitrogen consumed by cereals goes into the grains (Loomis & Connor, 1996), there is an argument that the cereals in a cereal-pea intercrop consume less nitrogen (leading to the outcome of reduced protein yields of cereal grains, see Table III). This argument does not, however, refute the assumption that the pea releases part of the atmospheric nitrogen, fixed by pea, into the soil during the vegetation period. Nevertheless, even if release of nitrogen occurs, the cereals are unable to consume it due to fierce competition.

Jensen et al. (2004) noted that if organic farming systems have limited possibilities for using manure, the growing of air-nitrogen fixing cultures should be introduced. Our results also show that considerably greater protein yields were gained with cereal-pea intercrops on non-nitrogen fertilized soil than with pure cereal crops. The oat-pea intercrop, of the three combinations in the study, produced the highest grain and protein yields. Wheat-pea intercrops produced yields that were marginally lower than those of the oat-pea mix. Based on this study, barley-pea mixes proved unsuitable. This may be due to the unsuitability of the selected barley cultivar.

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II

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ORIGINAL ARTICLE

Vetch-wheat crops are superior to vetch-oat crops in terms of protein yield

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Abstract

The formation of yield in two different combinations: vetch with wheat or oats, and the effect of vetch on yield potential of cereals has been investigated in Estonian field experiments over three years. We found that the inclusion of vetch seed in cereal seed and increase of its seed density led to considerable decrease in the yield of the cereal component ($R = 0.980$–0.998). The adverse effect of vetch on cereal yield led to a reduction in wheat yield by up to 1861 kg ha^{-1} on average for the three years, and in oats yield by up to 1413 kg ha^{-1}. One reason for the decreases in cereal yields was the formation of smaller grains in cereals under increased vetch seed densities. As a three-year average, the wheat 1000-seed weight decreased by up to 6.3 g while the corresponding figure for oats under identical conditions was 2.5 g. The inclusion of vetch in a crop and the increase of its seed density led to a substantial increase in the protein content of cereal grains. In oats, the change in grain protein content was smaller. At the same time, the maximum protein yield per area unit in cereals was obtained from their monocultures. In a mix with vetch, the amounts of nitrogen consumed by cereals decreased and protein yield of cereals per area unit reduced at higher vetch seed densities. Vetch-cereal mixes had an advantage over cereal monocultures as far as protein yield was concerned. In vetch-wheat and vetch-oats mixes the maximum protein yield was 500 kg ha^{-1} and 438 kg ha^{-1}, respectively, on average for the three years. Of the two combinations, vetch-oats mixed crop gave the highest yield of grain, whereas the higher mixed crop yield resulted from the oats component. Oats is somewhat more competitive with vetch than wheat. Vetch-wheat mixed crop gave the highest protein yield because the protein content of wheat grains was higher than oat grains. Legume-cereal mixes are particularly suited for the conditions of organic farming as they ensure a relatively good harvest and a high protein yield.

Keywords: *Avena sativa, intercropping, mixed crops, protein content, protein yield, seed density, seed weights of cereals, Triticum aestivum, Vicia sativa.*

Introduction

In the growing of legume-cereal mixes in the field, attempts are made to imitate natural plant communities, since the productivity of these is often greater than that of crops of individual species. As the location of above- and intra-ground plant organs and also biological needs of components of mixed crops are different to some extent, mixed crops may make better use of environmental sources for plant growth than sole crops. Legumes acquire most of their nitrogen needs from the air (Trenbath, 1976; Hauggaard-Nielsen et al., 2001). Above-ground material of vetch may contain up to 100 kg ha^{-1} fixed air nitrogen; however, during unfavourable years, the N fixation may be below 60 kg ha^{-1} (Mueller & Thorup-Kristensen, 2001). Similar results have been obtained in research by others (Papastylianou, 1999). The amounts of air nitrogen bound by papillionaceous plants may vary greatly, depending on the peculiarities of the vegetation period (Peoples et al., 2001). The accumulation of air nitrogen in the above-ground mass of vetch varied considerably, depending on the cultivation systems and fertilization. Binding of nitrogen was affected particularly favourably by fertilization with farmyard manure (Sidiras et al., 1999).

When papillionaceous plants are grown together with graminaceous plants, a part of the air nitrogen bound by nodule bacteria may be released into the soil and used for graminaceous plants in the same

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year. The phenomenon has been noticed in long-term grassland studies. It was noticed (Hogh-Jensen & Schjoerring, 1997) that air nitrogen bound by white clover is 'transferred to the associated ryegrass only starting from the second production year. In the first production year, the amounts of transferred N were not notable. However, there are data (Jorgensen et al., 1999) indicating that no considerable transfer of white clover N to grass occurred in the seeding year but the process occurred in the following years. Precise studies have established (Hogh-Jensen & Schjoerring, 2000) that very strong transference from white clover to grass occurs in the second and third years of production. At the same time, the amounts transferred from red clover to grass were smaller than with white clover. The transference of nitrogen from clover to grass was not affected by fertilization with nitrogen and grassland cutting intensity (Hogh-Jensen & Schjoerring, 1994). Release into soil of air nitrogen bound by legumes and its possible use by cereals has been studied in intercrops of legumes and cereals. In several cases, it could not be proved that air nitrogen bound by legumes in field conditions is transferred to the cereal component (Cowell et al., 1989; Jensen, 1996a). The study conducted on the basis of pot experiments revealed that part of the air nitrogen bound by pea was transferred to barley (Jensen, 1996b).

Legume-grain intercrops have produced higher seed and protein yields than sole grain crops (Hauggaard-Nielsen et al., 2001; Jensen, 1986, 1996a). In addition, legume-cereal mixed crops may provide yield advantages and create yield stability over years compared with pure stands of either legumes or cereals (Willey, 1979; Ofori & Stern, 1987). Vetch-wheat mixed crops have given greater yields if they followed grain and no mineral N fertilizers were used. Yield differences between wheat-vetch mixed crops and pure wheat crop were relatively small in the case of the pure wheat crop, and the mixed crop was fertilized with nitrogen (Lauk & Leis, 1997). Vetch has proved a good pre-crop for barley. The yield of barley and accumulation of nitrogen increased considerably compared with its cultivation after cereals (Danso & Papastylianou, 1992; Papastylianou, 1990, 2004). In a pea-barley intercrop, nitrogen fertilizer did not increase the mixed crop yield; moreover, fertilizing decreased the proportion of pea yield (Jensen, 1996a). In vetch-wheat mixed crops, N fertilization (N_{34} and N_{68}) decreased the vetch component's yield and increased the wheat component's yield and, therefore, the effectiveness of N fertilizer was modest in mixed crop fertilization (Lauk & Lauk, 2004). In general, the addition of legumes into the crop rotation is considered a pre-condition for improving the general productivity of the rotation (Yau et al., 2003).

On the basis of the above, the use of legume-grain intercrops would be particularly suitable in organic farming. The intercrops would, to some extent, replace mineral N fertilizers. To obtain reliable information on this assumption, it is necessary to carry out research with legume-grain mixed crops in different regions and environmental conditions.

This research aimed to study the effect of vetch-cereal mixes compared to wheat and oats monocultures in soil without N fertilizer. Another objective was to find practical solutions which could be introduced into production and to disseminate, by means of scientific research, information on vetch growing for the purpose of enhancing diversity in agriculture. At the theoretical level, we were interested in what was the effect of vetch on the yield potential of cereals and what it consisted of.

Material and methods

The field trial was conducted using the trial series method which allowed one replication. The data were processed and the trial error calculated by means of regression analysis (Lauk & Lauk, 2000; Lauk et al., 2004). In one trial series, spring vetch (variety 'Carolina') was grown mixed with spring wheat (variety 'Tjalve') and in a second trial vetch was grown mixed with oats (variety 'Jaak'). The sowing rate of the cereals was identical in all variants of the trial series – 250 germinating seeds per m^{-2}. According to this methodology, vetch seed densities varied in the trial series from 0 to 120 germinating seed per m^{-2}, at an interval of 12 germinating seeds per m^{-2}. Each trial series contained 11 different (quantitative) variants: 0, 12, 24, 36, 48, 60, 72, 84, 96, 108 and 120 germinating seeds per square metre. The variants in the trial series were in one replication, as the regression method enabled us to calculate experimental error in the case of one replication (Little & Hills, 1972; Mead et al., 1993). For untreated variants in the series (pure stands of cereals) were used in two trial plots, i.e., it was duplicated in both series. Two control figures for one series makes it easier to define the initial point of regression (Lauk & Lauk, 2000).

The field trials were carried out on a pseudopodzolic, moderately moist soil having a slightly sandy-clayey texture. The soil properties were as follows: pH_{KCl} of the ploughed layer was 4.9–6.1, organic matter content 2.3–3.2%, and the available phosphorus and potassium contents (determined using the AL method) were 76–174 mg kg^{-1} and 109–204 mg kg^{-1}, respectively. The preceding crop was spring wheat, and no fertilizers were used in the trial

years. The seeds of vetch and cereals in the mixed crop variants were sown into one and the same row using a special plot drill. The size of the trial plots was 10 m^2. The year 2002 proved difficult for crop growth, with an average air temperature higher than usual and total precipitation in the growth period being just 147 mm, approximately twice lower than normal. The years 2000 and 2001 had much more suitable conditions for crop growth, with the total precipitation in the growth period being 330 mm and 285 mm, respectively. After harvest, the yields were recorded both by their separate components and total yields. The yields were calculated at 14% moisture content. Additionally, the 1000-seed weight and crude protein content were determined for each variant. The yields of crude protein were calculated on the basis of dried yield and crude protein content in the dry components.

With all indicators, three years' averages were calculated in different variants of the experimental series. The processing of the three years' average data was performed by using regression analysis ($y = a + bx + cx^2$). The independent variable in the regression analysis was vetch seed density per m^{-2}, which varied between 0–120, and the dependent variable was, respectively: yield and protein yield (kg ha^{-1}), cereal 1000-seed weight (g) and cereal grain protein content (% in dry matter).

Standard errors (S.E.) and confidence limits ($CL_{0.05}$ – level of statistical significance, $p = 0.05$) were calculated using the relevant methodology (Lauk & Lauk, 2000). The reliability of the correlations in the trial series was evaluated using the control values of the correlation coefficients (R), which were taken from the corresponding tables based on the number of the degrees of freedom (df = 12 – 3) (Little & Hills, 1972).

Results

The regression analysis made with a personal computer gave the following equations and outputs:

1. For wheat seed yields (kg ha^{-1}): $y = 2782.8 - 30.446x + 0.1245x^2$, in which case $R^2 = 0.996$, S.E. = 11.7, $CL_{0.05} = 26$;
2. For oats seed yields (kg ha^{-1}): $y = 3013.2 - 17.947x + 0.0514x^2$, in which case $R^2 = 0.961$, S.E. = 28.5, $CL_{0.05} = 65$;
3. For seed yields of wheat-vetch mixes (kg ha^{-1}): $y = 2839.4 + 0.014x - 0.0661x^2$, in which case $R^2 = 0.952$, S.E. = 20.2, $CL_{0.05} = 46$;
4. For seed yields of oats-vetch mixes (kg ha^{-1}): $y = 3203.7 - 1.537x - 0.0413x^2$, in which case $R^2 = 0.961$, S.E. = 14.9, $CL_{0.05} = 33$;
5. For wheat 1000-seed weight (g): $y = 36.94 - 0.124x + 0.0006x^2$, in which case $R^2 = 0.977$, S.E. = 0.12, $CL_{0.05} = 0.3$;
6. For oats 1000-seed weight (g): $y = 35.41 - 0.033x + 0.0001x^2$, in which case $R^2 = 0.930$, S.E. = 0.07, $CL_{0.05} = 0.2$;
7. For wheat protein yields (with seeds, kg ha^{-1}): $y = 336.2 - 3.148x + 0.0105x^2$, in which case $R^2 = 0.992$, S.E. = 2.14, $CL_{0.05} = 5$;
8. For oats protein yields (with seeds, kg ha^{-1}): $y = 292{,}2 - 1.596x + 0.0049x^2$, in which case $R^2 = 0.934$, S.E. = 3.22, $CL_{0.05} = 8$;
9. For protein yields of wheat-vetch mixes (with seeds, kg ha^{-1}): $y = 351.0 + 4.866x - 0.0396x^2$, in which case $R^2 = 0.906$, S.E. = 5.09, $CL_{0.05} = 12$;
10. For protein yields of oats-vetch mixes (with seeds, kg ha^{-1}): $y = 342.0 + 2.747x - 0.0196x^2$, in which case $R^2 = 0.743$, S.E. = 5.66, $CL_{0.05} = 13$;
11. For wheat seed protein content (% in DM): $y = 13.67 + 0.045x - 0.0002x^2$, in which case $R^2 = 0.983$, S.E. = 0.05, $CL_{0.05} = 0.1$;
12. For oats seed protein content (% in DM): $y = 11.43 + 0.002x + 0.00007x^2$, in which case $R^2 = 0.914$, S.E. = 0.04, $CL_{0.05} = 0.1$.

The equations obtained with statistical data processing enables calculation of yields and results of other indicators with any vetch sowing rates ranging between 0 and 120 vetch seeds per square metre, which, at the same time, is an advantage for the regression analysis. To avoid excessive numbers, results have been calculated for the sowing rates 0, 20, 40, 60, 80, 100 and 120 vetch seeds per 1 m^2. In Table I, seed yields of wheat and oats have been calculated by the equations 1 and 2, respectively, seed yields of mixed stands by the equations 3 and 4, and 1000-seed weight of cereals by the equations 5 and 6.

The data presented in the table reveal that, in soil with no N fertilizer, the pure oats stand gave a higher grain yield than the pure wheat stand. The inclusion of vetch in cereal seed and the increase of vetch seed density led to substantial reductions in the cereal yields. Owing to the adverse effect of vetch on cereal yield the three-year average yield of wheat decreased by up to 1861 kg ha^{-1} and that of oats by up to 1413 kg ha^{-1}. The correlations between vetch seed density and cereal yield were very strong ($R = 0.980$–0.998; $p < 0.001$).

At the lowest vetch seed density the yield of vetch-cereal mixes was quite close to the yields of monoculture cereals. Higher vetch seed densities led to increasing yield reductions in vetch-cereal mixes.

Table I. The formation of seed yields and 1000-seed weights in cereals, and of seed yields of vetch-cereal mixes depending on vetch seed densities on average for the three years.

Seeding rate of vetch, seeds m^{-2}	Yield (kg ha^{-1})				1000-seed weight (g)	
	of wheat	of wheat+vetch mixes	of oats	of oats+vetch mixes	Wheat	Oats
0	2783	–	3013	–	36.9	35.4
20	2224	2813	2675	3156	34.7	34.8
40	1764	2734	2378	3076	32.9	34.3
60	1404	2602	2121	2963	31.7	33.8
80	1144	2417	1906	2816	30.9	33.4
100	983	2180	1733	2637	30.6	33.1
120	922	1889	1600	2425	30.7	32.9
S.E	12	20	28	15	0.12	0.07
$CL_{0.05}$	26	46	65	33	0.3	0.2

The correlations between vetch seed densities and mixed crop yields were very close ($R = 0.976$–0.980; $p < 0.001$). In vetch-oats mixes the per-hectare yield was higher by 343–536 kg than in vetch-wheat mixes ($p < 0.05$). The higher yield was attributable to the oats component.

The inclusion of vetch in cereal seed and the increase of vetch seed density led to considerable decreases in cereal 1000-seed weights ($R = 0.964$–0.988; $p < 0.001$), which was one of the reasons for the reduced cereal yields. The 1000-seed weight decreased by up to 6.3 g in wheat and by 2.5 g in oats under identical circumstances. This demonstrates that for cereals the conditions for seed formation and filling were worse in a mix with vetch than in monocultures. Oats is somewhat more competitive with vetch, and therefore the reduction in the 1000-seed weight (and the yield) attributable to increased vetch seed density is not as great in oats as it is in wheat.

In Table II, protein yields of cereals (contained in the grain) per area unit have been calculated by using equations 7 and 8, protein yields of mixed crops (contained in the grain) by using equations 9 and 10 and protein content of cereal grain by using the equations 11 and 12. The data reveal that the grain protein content in wheat and oats was 13.7% and 11.4% of dry matter, respectively. The protein content of cereal grains increased considerably at higher vetch seed densities ($R = 0.956$–0.992; $p < 0.001$). The protein content of wheat and oats grains grew by 2.5% and 1.5%, respectively. The protein content of wheat grain was higher than that of oats grain by 2.3–4.0%, depending on the vetch seed density. The protein content of vetch seeds ranged from 31.1 to 31.4% of dry matter on average for the three years and for all the trial variants.

The protein yields per area unit of the cereals were highest in monocultures. The inclusion of vetch in cereal seed and the increase of its seed density had a very strong adverse effect on the protein yields of the cereals (the amount of nitrogen contained in the cereal grain). The correlations were very strong and reliable ($R = 0.966$–0.996; $p < 0.001$). In a mix with vetch, the protein yield of wheat seeds decreased by up to three times and that of oats by up to 1.7 times. At the same time, in a monoculture or at lower vetch seed densities the yields of oats contained less protein than that of wheat on average for the three years. At higher vetch seed densities the situation was reversed, which again testifies to a higher competitiveness of oats with vetch in mixed crops.

Table II. The protein contents and yields per area unit of cereal grains and the protein yields of seed of vetch-cereal mixes depending on the vetch seed density on average for the three years.

Seeding rate of vetch, seeds m^{-2}	Protein yield (kg ha^{-1})				Protein content of grains (%)	
	of wheat	of wheat+vetch mixes	of oats	of oats+vetch mixes	Wheat	Oats
0	336	–	292	–	13.7	11.4
20	278	432	262	389	14.5	11.5
40	227	482	236	420	15.1	11.6
60	185	500	214	436	15.6	11.8
80	152	487	196	436	16.0	12.0
100	126	442	182	421	16.2	12.3
120	110	365	171	389	16.2	12.7
S.E	2.1	5.1	3.2	5.7	0.05	0.04
$CL_{0.05}$	5	12	8	13	0.1	0.1

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The vetch-cereal mixes proved effective in terms of protein yield. The inclusion of vetch in cereal seed led to substantial increases in protein yields ($R = 0.862$–0.952; $p < 0.01$ and < 0.001). The maximum protein yields of a vetch-wheat mix (500 kg ha^{-1}) and a vetch-oats mix (438 kg ha^{-1}) were obtained at a vetch seed density of 60 germinating seeds per square metre. Higher vetch seed densities led to increasing reductions in the protein yields of the vetch-cereal mixes.

Discussion

In our previous studies, monoculture wheat yielded 1982 kg of grain per ha^{-1} as the average for the three varieties. In the vetch-wheat mixed crops the maximum yield level was up to 3248 kg ha^{-1}, depending on the wheat variety. At the same time, the agronomically maximum yield of vetch-oats mixes was up to 4621 kg ha^{-1} and the maximum possible extra yield compared to monocultural oats was 1668 kg ha^{-1}. Such yield levels of mixed crops were attained when cereal seeds were combined with 64–74 germinating vetch seeds per m^{-2} (Lauk et al., 1999). In this study, wheat and oats monocultures yielded 2783 kg of grain per ha^{-1} and 3013 kg of grain per ha^{-1}, respectively. As the yield level of monocultures was relatively high compared to that mentioned above, mixed crops had no advantage over cereal monocultures as far as yield was concerned.

On average for the three years, the protein yield of monoculture oats was somewhat lower than that of monoculture wheat. The situation was reversed with regard to grain yields, with oats producing a higher yield than wheat. Considering that the trial was performed on a soil where no nitrogen fertilizers were applied, there are two possible reasons for our results. On the one hand, oats is regarded as a less demanding species; hence it should produce higher yields than other cereals even in unfavourable conditions (Burrows, 1986). On the other hand, the fact that oats produces higher grain yields than wheat on a soil with no nitrogen fertilization may be due to the fact that oats has a smaller need for nitrogen during the period of grain formation. The need for nitrogen is smaller because the content of nitrogen compounds in grain yield of sole crops is considerably lower in oats than in wheat (Table II).

When we started this study we assumed that the capacity of the vetch component to fix atmospheric nitrogen would also benefit the cereal component in a mixed crop, i.e., that part of the atmospheric nitrogen fixed by vetch may in the second half of the vegetation period be released into the soil for consumption by cereals, thus improving the conditions for cereal nitrogen nutrition. As 70% of the nitrogen consumed by cereals goes into the grains (Loomis & Connor, 1996), it may be thought that in a mix with vetch the amounts of nitrogen consumed by cereals would be decreased. However, this does not allow for the fact that part of the atmospheric nitrogen fixed by vetch is released into the soil during the vegetation period. The competition revolves around the use of photosynthetically active solar radiation. In the second half of the vegetation period, following the formation of grains, the placement of vetch leaves is such as to keep the lower stalk segments and leaves of cereals in their shade. The situation is even worse at higher vetch seed densities. The lower opportunities for cereals to use photosynthetically active radiation hinder non-nitrogenous synthesis of extractive substances in cereals during the period of grain formation and filling. As a result, cereals grown in a mix with vetch produce considerably smaller grains (outcome – substantial reductions in the 1000-seed weight and lower yields, Table I), in which the proportion of nitrogen compounds is high (outcome – considerably higher protein content in the grains, Table II). It appears also that experiments carried out in other countries have shown that N concentration in grain increased when the grain was grown together with legumes (Knudsen et al., 2004).

Some suggestions for mixed crop growers using vetch as the legume component could be as follows: when growing vetch for seed it is preferable to use wheat as the cereal component in the mix; when growing vetch for feed, oats are preferred as the support crop. Legume-cereal mixes are particularly suited for conditions of organic farming. The inclusion of vetch in cereal seed led to substantial increases in protein yields. In vetch-wheat and vetch-oats mixes the maximum protein yield was, in our conditions, 500 kg ha^{-1} and 438 kg ha^{-1}, respectively on average for the three years.

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Yields in vetch-wheat mixed crops and sole crops of wheat

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Abstract. Field trials with common vetch (*Vicia sativa* L.) and spring wheat (*Triticum aestivum* L.) mixes were conducted from 1994 to 2004 on pseudopodzolic moderately moist soils in the trial fields of the Institute of Agricultural and Environmental Sciences of the Estonian University of Life Sciences at Eerika, outside Tartu (58º 23´ N, 26º 44´ E). The results of the research showed that in cases where the yields of post-cereal wheat monocultures were 1500–3000 kg ha^{-1} vetch-wheat mixed crops (at the seed densities of 50 germinating vetch seeds and 250 germinating wheat seeds per m^2) guaranteed an approximate harvest of 3000 kg ha^{-1}, even under no nitrogen fertilisation, provided the total amount of precipitation in the growth period was 300 ± 50 mm. If the yields of monocultural wheat topped the level of 3000 kg ha^{-1}, mixed crops, however, lost their advantage over wheat monocultures as the latter's grain harvests were greater in those cases. Vetch-wheat mixed crops maintained their advantage over sole crops of wheat insofar as protein yields were concerned, primarily due to the high protein content of vetch. The extra gain in the protein yields of mixed crops compared to wheat monocultures was 100–500 kg ha^{-1} in our study, and was heavily dependent on the protein levels monocultural wheat was able to produce in each particular case.

Key words: mixed crops, common vetch, wheat, yield, protein yield

INTRODUCTION

The inclusion of common vetch in a crop rotation is considered a precondition to increasing the overall production of the crop rotation (Yau et al., 2003). Under suitable circumstances, vetch is capable, with the help of *Rhizobaceae*, of fixing atmospheric nitrogen (Mueller & Thorup-Kristensen, 2001). Half of the amount of the nitrogen fixed will satisfy the nitrogenous requirement of vetch itself and the other half will be left over for succeeding crops. The growing of vetch in a monoculture is questionable as its plants are susceptible to lodging. Furthermore, weeds reduce the seed yield of monocultural vetch by up to 71% (Dimitrova, 1997). Accordingly, spring vetch should be grown in a mix with support crops. Of cereals, wheat, oats and triticale would make a suitable support culture for vetch (Sobkowicz & Śniadu, 2000; Ceglarek et al., 2004). Support crops shorten the growth period of vetch, promote more even ripening of vetch seeds and reduce the extent of lodging of the legume crop.

The advantage of growing vetch and wheat together is that vetch has a well-developed taproot system while wheat has a hair root system. Therefore, they do not compete with each other for nutrients available in the soil. Vetch-wheat mixes have also been reported to produce higher seed and protein yields than cereal monocultures (Jensen, 1996), even under circumstances where they succeed a cereal crop and no use is made of mineral nitrogen fertilisers (Lauk et al., 1999). Thus, the growing of mixed crops would first and foremost be suitable for ecological methods of farming, simultaneously serving, to a certain extent, as a substitute for mineral nitrogen fertilisers.

During the period of study, we obtained fairly controversial results for the yields of vetch-wheat mixed crops. Therefore, the objective of this paper was to establish the conditions in which intercrops of vetch and wheat produce greater seed harvests than wheat in pure stands, and the efficiency of vetch-wheat mixes as regards protein yield. We also tried in our study to identify the correlation between the total precipitation in the growth period and the seed yield of the vetch-wheat mix.

MATERIALS AND METHODS

Field trials with spring vetch-spring wheat mixed crops were conducted from 1994 to 2004 on pseudopodzolic moderately moist soils in the trial fields of the Institute of Agricultural and Environmental Sciences of the Estonian University of Life Sciences at Eerika, outside Tartu. Properties of the soil: pH_{KCl} 5.8 to 6.2, content of organic matter 2.8 to 3.2%, content of elements in A horizon: available (AL method) P 145 to 174 mg kg^{-1} and K 150 to 180 mg kg^{-1}. Phosphor and potassium fertilisers were not used in the trials, since the experimental soils' need for P and K was small. In all years, the preceding crop was spring wheat fertilised with N_{60}.

The efficiency of the mixes was investigated by analysing the field trials, in which common vetch (variety 'Carolina') was grown in combination with different spring wheat varieties ('Tjalve', 'Meri' or 'Helle'), both under no nitrogen fertilisation and on soils fertilised with nitrogen (N_{34}, N_{50} or N_{68}). Therefore, the data for 1995, 1996 and 1998, when the mixes were preceded by other crops not meeting the requirements, were excluded from the analysis. The data for 1999 and 2002, when the vegetation period was extremely dry and with relatively high air temperatures, were excluded from the investigation of mixed crop efficiency as these years were extremely unfavourable for vetch growth. However, the data for these years were used in determining the correlation between the amount of precipitations and mixed crop seed yields. Only data from soils without nitrogen fertiliser were used in the determination of the correlation.

Information about the weather was obtained from the Eerika Meteorolocical Station near Tartu. Protein content was determined in the Laboratory of Plant Biochemistry of the Estonian University of Life Sciences by using Kjeltec's apparatus and Tecotar AN assessment methods (Nx6.25). The yields of crude protein were calculated on the basis of desiccated yield and crude protein content in the dry components. The yields were calculated at 14% water content.

Vetch-wheat mixed crop efficiency was investigated using, on the one hand, monocultural wheat variants and, on the other hand, vetch-wheat mixed crop variants, in which the densities of the components in the seed mix were 50 germinating vetch seeds per square metre and 250 germinating wheat seeds per square metre, respectively. The difference between the yields of the vetch-wheat mixes and the wheat monocultures were calculated, and the data were processed using linear regression analysis ($y = a + bx$). The values of x were wheat monoculture yields and those of y were the differences between the yields of vetch-wheat mixes and wheat monocultures.

The correlation between precipitation levels and vetch-wheat mixed crop yields was determined using the quadratic equation ($y = a + bx + cx^2$), in which the argument (x) was the amount of precipitation during the period of mixed crop growth and the argument function (y) was the vetch-wheat mixed crop yield in kilograms per hectare.

The reliability of the correlations in the trial series was evaluated using the control values of correlation coefficients (R) taken from corresponding tables based on the number of degrees of freedom (Little & Hills, 1972). In the article, use was also made of the following symbols:

R^2 – determination coefficient;

n – sample size; in regression analysis, number of pairs of comparison;

P – level of statistical significance.

RESULTS AND DISCUSSION

In the first years of our research (1994, 1997), vetch-wheat mixes yielded greater harvests than wheat monocultures (by 803–1100 kg per hectare) in cases where the preceding crop was a cereal and no fertilisers were applied (Lauk et al., 1999). Under fertilisation with nitrogen (N_{34}), however, differences in yield between mixed crops and wheat monocultures were much smaller (210–295 kg ha^{-1}). At subsequent stages of the research it appeared, however, that in four consecutive years (1999–2002) vetch-wheat mixed crop yields were smaller under no nitrogen fertilisation than wheat monoculture yields. Thus the findings did not corroborate our previous conclusions. We assumed that the reason were the relatively high yield levels of wheat or the low precipitation levels during the growth periods. The regression line and the regression equation in Fig. 1 demonstrate that our first premise was true.

The efficiency of post-cereal vetch-wheat mix, i.e. the issue of whether or not mixed crops produce higher yields than wheat monocultures, depends heavily on the yield level of monocultural wheat. If the amount of nitrogen available to wheat allows monocultural wheat to reach yield levels in the excess of 3000 kg ha^{-1}, vetch-wheat mixes lose their advantage and yield even smaller harvests than wheat monocultures. At monocultural wheat yield levels exceeding 3000 kg ha^{-1} there were only three occasions out of 14 when the yield levels of mixed crops slightly surpassed those of wheat monocultures. In 2000 and 2001, monocultural wheat produced relatively high grain yields (over 3000 kg ha^{-1}) even under no nitrogen fertilisation. As the result, most of the yields of vetch-wheat mixes were lower than those of wheat monocultures. Consequently, the nitrogen nutrition conditions in these years were relatively favourable to wheat on soils with no nitrogen fertilisation.

If monocultural wheat yield levels fell between 1500–3000 kg ha^{-1} then vetch-wheat mixes produced greater yields than wheat monocultures. The efficiency of vetch-wheat mixed crops was the greater the lower was the sole crop of wheat seed yields. In cases where monocultural wheat seed yields failed to reach the level of 3000 kg ha^{-1} vetch-wheat mixes produced a yield of approximately 3000 kilograms per hectare. It may be concluded from the figure (Fig. 1) that at monocultural wheat seed yield levels of 1500 kg ha^{-1} the efficiency of the mixed crops was slightly over 1500 kg ha^{-1} (i.e., exceeded the monocultural wheat yield levels by that amount).

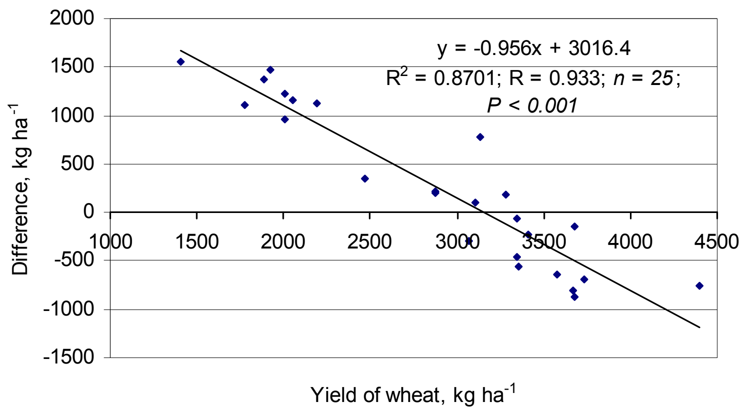

Fig. 1. Difference between the yields of vetch-wheat mixes and wheat monocultures.

At monocultural wheat seed yield levels of 2000 kg ha^{-1} the efficiency of the mixed crops was slightly over 1000 kg ha^{-1}. In general, a 1-kilogram change in wheat seed yield corresponds to a 0.96-kilogram change in vetch-wheat mixed crop efficiency. Consequently, vetch-wheat mixed crops are suitable under organic farming circumstances in which no mineral nitrogen fertilisers are used.

It must also be emphasised that this rule applies where both wheat monocultures and vetch-wheat mixed crops are preceded by a cereal crop. It does not apply where the crops under study are preceded by other crops (Lauk et al., 1999).

A second reason why mixed crop seed yields were lower than those of monocultural wheat were the precipitation levels during the growth period. Previous studies on the effect of weather conditions on the growth and development of the legume component in a mixed crop showed that in a droughty year legume generally produced a lower seed yield in a mixed crop while in a rainy year it produced a higher yield (Guilioni et al., 2003). At the same time, no studies have been performed on vetch sowing time in Estonia whereas in regions more to the south (Turkey) it is recommended that vetch be sown as early as possible since this is the only option for obtaining maximum seed or green biomass yields per hectare (Temel & Tan, 2002; Cakmakci et al., 2002).

It may be concluded from the correlation given in Fig. 2 that when preceded by a cereal crop vetch-wheat mixes produce yields of approximately 3000 kg per hectare provided the total precipitation in the growth period is 300 ± 50 mm. In the period under study the driest year was 1999, when the total precipitation in the mixed crop growth period was below 100 mm and the average air temperature was higher than the average. Therefore, vetch was early to complete its growth in mixed crops, and seeds in vetch pods ripened already by 24 July (the trial crops were sown on 24 April, wheat sprouted on 5 May and vetch on 7 May), i.e. 3–4 weeks earlier than usual. The wheat

in the mixed crops ripened by 28 July, i.e. 4 days later than vetch. The mixed crop components were able to take up nutrients and synthesise organic matter in a considerably shorter period, notwithstanding the extreme weather conditions. The yields of the mixed crops fell below 1000 kg ha^{-1} (the lowest point in the correlation table).

The year 2002 was likewise characterised by dry weather (the total precipitation in growth period 150 mm) and relatively high air temperatures. As the result, the mixed crop yields remained below 2000 kg ha^{-1} (second lowest point in the correlation table). The vetch in the mixed crops ripened by 1 August (the trial crops were sown on 17 April), 3–4 days earlier than wheat. The correlation also incorporates, in essence, the higher-than-the-average air temperatures in the vegetation periods of the two above-mentioned years since the crops ripened and were harvested so early that the rainfall data for August could not be included. In other years, the total growth-period precipitation levels were higher because part of the August precipitation was also taken into account. In droughty years, vetch grown in a mix with wheat remained in the low-level. In the years with average air temperatures and precipitation levels, vetch came to maturity a few days later than wheat.

When preceded by a cereal crop, vetch-wheat mixed crops are fairly promising under organic farming, in which no use is made of industrial mineral fertilisers. Under conventional farming, in turn, vetch-wheat mixes help to save on mineral fertiliser purchase costs. In the first half of the research, post-cereal wheat monoculture yields under no nitrogen fertilisation were approximately 2000 kg ha^{-1} (Lauk et al., 1999).

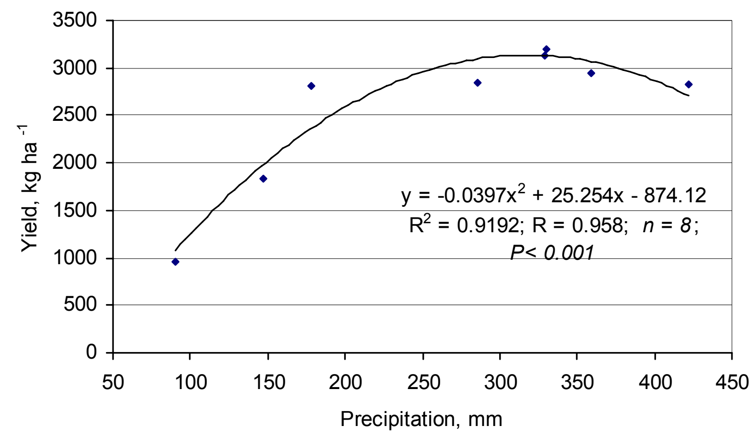

Fig. 2. Dependence of vetch-wheat mixed crop yields on precipitation levels in the growth period (from sowing to harvesting).

Accordingly, vetch-wheat mixes produce higher yields than wheat monocultures by about 1000 kg (see Fig. 1), except in droughty years. Based on the average efficiency of nitrogen fertilisation (N_{68}) in monocultural wheat (7.8 kg of grains per 1 kg of nitrogen), as evident from research (Lauk & Lauk, 2003), it may be maintained that the increasing of monocultural wheat yields by 1000 kg per hectare to reach the margin of 3000 kg ha^{-1} would require approximately 140 kg of nitrogen per hectare.

Vetch-wheat mixes are particularly efficient with regard to protein yield, primarily due to the high protein content of vetch (30.0–30.6 % in dry matter according to our data). It may be concluded from Fig. 3 that sole crop of wheat protein yields in the trials ranged between 175–480 kg ha^{-1} (Fig. 3). In cases where wheat yields and wheat protein yields remain low due to inadequate nitrogenous nutrition of wheat, post-cereal vetch-wheat mixes produce protein yields of 600–700 kilograms per hectare. The extra gains in protein yield obtained from mixed crops compared to wheat monocultures were 100–500 kg ha^{-1} in our study, and were heavily dependent on the protein levels monocultural wheat was able to produce in each particular case.

To make up for the difference, and in order for wheat monocultures to produce protein yields equal to or even greater than those of mixed crops, the protein yields of monocultural wheat must be approximately 550 kg ha^{-1}. This presupposes seed harvests exceeding 4500 kilograms per hectare. Such yield levels would require nitrogen fertilisers in fairly great quantities. In our study, the maximum level of nitrogen fertilisation was 68 kg of N per hectare. At such fertilisation rates, the three-year average protein yields of wheat monocultures were 480 kg ha^{-1} at the maximum (Lauk & Lauk, 2003). Consequently, where it may be assumed that the particular circumstances would not be conducive to sufficiently high cereal yields when the preceding crop is a cereal (N-fertilisers are little or not at all used), vetch-wheat mixed crops are suitable to be grown as fodder. They will produce fairly sufficient harvests and protein yields under the soil and weather conditions prevalent in Estonia.

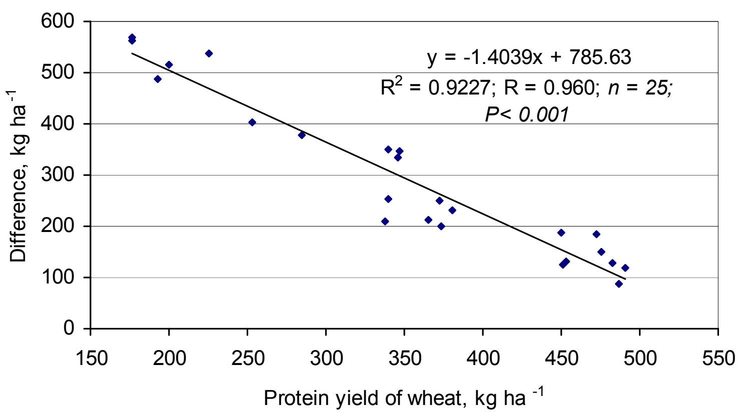

Fig. 3. Differences in protein yields between vetch-wheat mixed crops and wheat monocultures.

CONCLUSIONS

In cases where the yields of post-cereal wheat monocultures were 1500–3000 kg ha^{-1} vetch-wheat mixed crops (at the seed densities of 50 germinating vetch seeds and 250 germinating wheat seeds per m^2) guaranteed an approximate harvest of 3000 kg ha^{-1}, even under no nitrogen fertilisation, provided the total amount of precipitation in the growth period was 300±50 mm. If the yields of monocultural wheat topped the margin of 3000 kg per ha^{-1} mixed crops, however, lost their advantage over wheat monocultures.

Vetch-wheat mixes are particularly efficient with regard to protein yield, primarily due to the high protein content of vetch. In cases where wheat yields and wheat protein yields remain low due to inadequate nitrogenous nutrition of wheat, post-cereal vetch-wheat mixes produce protein yields of 600–700 kilograms per hectare. The extra gains in protein yield obtained from mixed crops compared to wheat monocultures were 100–500 kg ha^{-1}.

When preceded by a cereal crop, vetch-wheat mixed crops are fairly promising under organic farming, in which no industrial mineral fertilisers are used. Under conventional farming, in turn, vetch-wheat mixes help to save on mineral fertiliser purchase costs.

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THE YIELDS OF LEGUME–CEREAL MIXES IN YEARS WITH HIGH–PRECIPITATION VEGETATION PERIODS.
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THE YIELDS OF LEGUME – CEREAL MIXES IN YEARS WITH HIGHT – PRECIPITATION VEGETATION PERIODS

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Abstract

A research where common vetch (*Vicia sativa*) and pea (*Pisum sativum*) were grown together with either spring wheat (*Triticum aestivum*) or oats (*Avena sativa*) was conducted in experimental fields of the Department of Field Crop Husbandry of the Estonian Agricultural University in 2003 and 2004. The summer with high precipitation caused an intense vegetative growth of legumes and, therefore, cereals grown together with legumes remained in the lower front. Starting from a legume sowing rate of 60 germinating seeds per m^{-2}, downpour in July caused heavy lodging of legume-grain mixed crops in both experimental years. The average data of the two years show that, to ensure maximum yield, the amount of vetch added in mixed crops of grain should be considerably small in years of high precipitation. The optimum sowing rate of vetch mixed with wheat and oats was 30–50 germinating seeds per m^{-2} in the area, which ensured yields bigger by 800 kg ha^{-1} in the same conditions as grain pure crops. The optimum sowing rate of pea was 70–90 germinating seeds per m^{-2} when mixed with wheat and 60–80 germinating seeds per m^2 when mixed with oats. The mixed crops of vetch and oats gave higher yields than vetch-wheat mixed crops. The yields of pea-oats mixed crops reached a maximum of 3500 kg ha^{-1}, which is by 700 kg ha^{-1} more than the yield of pea-wheat mixed crops.

Key words: common vetch, pea, spring wheat, oats, yield, legume-cereal mixed crop

Introduction

Studies have shown that vetch-wheat mixes need practically no nitrogen fertilisation as the efficacy of a nitrogen fertiliser in a mixed crop is modest, particularly with regard to protein yield. Nitrogen fertilisation decreases the share of vetch in the yield of the mixed crop since the effect of a nitrogen fertiliser on the seed-producing capability of the vetch component is negative (Lauk *et al.*, 2003; Lauk *et al.*, 2004a).

Although we have engaged ourselves in studies of legume-cereal mixes for many years and the results of the research have been published in several articles (Lauk *et al.*, 1997; Lauk *et al.*, 1999; Lauk *et al.*, 2001), we still continue the studies of legume-cereal mixed crops as a number of issues are yet to be resolved. In our studies we assume that legume-cereal mixes produce a relatively high and protein-rich yield even under no use of mineral nitrogen fertilisers. We try to find out the best combinations for different circumstances and the optimal seed densities for different combinations. On the theoretical plane, we are interested in inter-species (legume-cereal-weed) and intra-species competition for plant growth factors in mixed crops.

In the present article, the results from the 2003 and 2004 mixed crop trials are considered in more detail. In the said years the level of precipitation during the growth period of the mixed crops was higher than usual; as a result, some new regularities were observed.

Materials and Methods

The study, in which spring vetch and pea were grown in a mix with either spring wheat or oats, was performed in accordance with the methods worked out at the Department of Field Crop Husbandry of the Estonian Agricultural University (Lauk *et al.*, 2004b). The field trials involved a total of five series: common vetch + spring wheat; vetch + wheat under nitrogen fertilisation (N_{50}); vetch + oats; pea + wheat and pea + oats. Pursuant to the methodology, the seed density of the cereals was identical in all the variants of the trial series: 250 germinating seeds per m^{-2}. The seed densities of vetch and pea varied in all the trial series from 0 to 120 germinating seeds per m^{-2} (a total of 11 different variants of legume seed density in each trial series). The interval between the different variants was 12 germinating legume seeds per m^{-2}. The variants were places at random in the trial series, with the area of a trial plot being 10 square metres. The mixed crops of vetch-cereal and pea-cereal were placed in two different blocks in a trial, with soil fertility differing from one block to the other. For this reason the yields of vetch-cereal and pea-cereal mixes are treated separately in the article.

The trials were performed on the trial fields of the Estonian Agricultural University at Eerika, outside Tartu, Estonia, on pseudopodzolic soil, which in the international WRB classification are called Albeluvisols (Kõlli *et al.*, 1999). The soil properties were as follows: pH_{KCl} of the ploughed layer was 5.05–5.39, organic matter content was 2.16–2.48%, and the available phosphorus and potassium contents (determined using the AL method) were 74.3–112.9 mg kg^{-1} and 83.6–143.8 mg kg^{-1}, respectively. No phosphorus or potassium fertilisers were applied to the mixed crops. The crop preceding the mixed crops was wheat.

Both 2003 and 2004 were characterised by high precipitation in summer. The precipitation rates during the mixed crop growth periods totalled 360 mm in 2003 and 420 mm in 2004. The usual precipitation rate, calculated from a long-time average, is 250 mm. The year 2004 was different in that the spring was relatively dry until early June. In both years the air temperature was relatively low in June.

The rainfalls in July (the precipitation rate exceeding 100 mm in both years) led to heavy lodging of legume-cereal mixes having legume seed densities of 60 germinating seeds per square metre or higher at the end of the second decade of the month in both trial years. No lodging until the harvest was observed in cereal monocultures and in the mixed crop variants where legume seed was included in cereal seed at the rate of 12 germinating seeds per m^{-2}. Relatively low lodging was observed in variants where the legume seed density was 24, 36 and 48 germinating seeds per square metre. Fertilisation with a relatively modest amount of nitrogen (N_{50}) led to a minor reduction in the intensity of mixed crop lodging.

After harvest, the yields were recorded both by their separate components and as total yields. The yields were calculated at a 14% water content. Additionally, the 1000 seed weight was determined for each variant.

The yield data obtained after the implementation of the trial were processed using regression analysis according to the following generalising equation:

$$y = a + bx + cx^2,$$

where: y – the argument function (yield of legume-cereal mix, kg ha^{-1}; 1000 seed weight, g);
a – the absolute term (constant) of the regression;
b and c – regression coefficients;
x – the argument (legume seed density, germinating seeds per m^{-2}).

The correlations between the legume seed density and the mixed crop yield as well as the 1000 seed weight were very strong in all the trial series as demonstrated by the numerical values of the correlation coefficients (R), and had a 99% reliability. All the data presented in the tables were calculated from equations derived from regression analysis. To evaluate the reliability of the differences between the trial series the least significant differences were calculated in accordance with the methodology (Lauk *et al.*, 2004b) at a 95% reliability level.

Results and Discussion

The maximum yields of wheat and oats were obtained from the monocultures of the cereals (Table 1). The inclusion of vetch seed in cereal seed and the increasing of vetch seed density very strongly reduced the yield of cereals in the high-precipitation years. The correlations between the vetch seed densities and the cereal yields were very strong (R = 0.990–0.994). As the crops experienced heavy lodging at higher vetch seed densities (over 50 vetch seeds per m^{-2}) and the conditions were unfavourable during the time of grain formation and filling in cereals, the yields of the cereals were several times smaller. The application of a nitrogen fertiliser lead to an increase in wheat productivity in both a monoculture and a mix with vetch. Oats as a less pretentious crop exceeded wheat by productivity in both a monoculture and a mix. The difference in the yields at vetch densities of up to 60 germinating seeds per square metre constituted slightly over 1100 kg ha^{-1} in favour of oats.

Vetch productivity was high starting already from low vetch seed densities. At the vetch seed density of 20 germinating seeds per m^{-2}, vetch yielded 1420–1770 kg ha^{-1}, depending on the trial series. Compared to the control series, fertilisation with nitrogen and mixing with oats led to a reduction in vetch yield at the said vetch seed density. The greatest vetch yields were obtained under no nitrogen fertilisation in a mixed crop with wheat or oats at vetch seed densities of 50–70 seeds per m^{-2}. Further increases in vetch seed density led to considerable reductions in vetch productivity. Nitrogen fertilisation led to decreased vetch yields at lower seed densities compared to the control series but increased the yields at high vetch seed densities, with the maximum yield of vetch being obtained at the maximum vetch seed density.

Table 1. Yield formation in cereal monocultures and in vetch-cereal mixes at different vetch seed densities and a comparison of different trial series (two-year averages, kg ha^{-1})

Seeding rate of vetch, seeds per m^{-2}	Vetch + wheat, yield (check)	Vetch + wheat + N_{50}		Vetch + oats	
		yield	difference	yield	difference
		yield of cereals			
0	1938	2400	463	3053	1115
20	1375	1884	508	2555	1180
30	1136	1658	522	2323	1186
40	926	1454	528	2102	1176
50	744	1271	528	1892	1148
60	590	1110	521	1693	1104
70	464	971	507	1506	1042
100	256	681	425	1010	754
120	258	596	338	736	477
		$LSD_{95\%}$	105		115
		yield of vetch			
20	1772	1635	–137	1421	-351
30	1930	1747	–183	1621	-309
40	2046	1850	–197	1778	-268
50	2120	1941	–179	1892	-228
60	2152	2022	–130	1964	-188
70	2143	2093	–50	1994	-148
100	1861	2241	380	1828	-33
120	1463	2287	824	1505	42
		$LSD_{95\%}$	111		104
		total yield of vetch-cereals mixes			
20	2711	3066	355	3682	972
30	2817	3148	331	3776	959
40	2874	3204	330	3814	940
50	2882	3234	352	3797	916
60	2840	3238	397	3725	885
70	2749	3214	465	3597	848
100	2181	2988	807	2880	699
120	1555	2704	1,149	2125	570
		$LSD_{95\%}$	260		238

The maximum yields of the mixed crops (2840–2880 kg ha^{-1}) were obtained from the control series (vetch + wheat) at vetch seed densities of 40–60 germinating seeds per m^{-2}. At its maximum, the per-hectare yield of the vetch-wheat mix was approximately 950 kg greater than that of wheat monoculture. Under nitrogen fertilisation the vetch-wheat mix produced the maximum yields (slightly over 3200 kg ha^{-1}) at vetch seed densities of 50–70 seeds per m^{-2}, and the per-hectare yield of the mix exceeded that of monocultural wheat by 800 kg.

The yields of vetch-oats mixes were considerably greater than those of vetch-wheat mixes, with the margin attributable to the oats component. The maximum yields in the said crops (approximately 3800 kg ha^{-1}) were obtained at vetch seed densities of 30–50 germinating seeds per m^{-2}. The mixes produced per-hectare yields that exceeded those of monocultural oats by up to 800 kg.

The results of the research suggest that in a high-precipitation year vetch-cereal mixes should be set up by including relatively small amounts of vetch seed in cereal seed. As the weather conditions are unpredictable in spring, the results of the research may be generalised for wetter growth sites. On wetter growth sites, accordingly, vetch-cereal (oats, wheat) mixed crops should be set up by including relatively small amounts of vetch seed in cereal seed, for under wetter circumstances the vegetative growth of vetch is very intensive and its competitiveness with cereals is high. On a wetter growth site, vetch seed should be added to oats and wheat seed at the rate of 30 germinating seeds per m^{-2}; higher vetch seed densities, while potentially conducive to even greater yields, raise the risk of crop lodging.

As regards the pea-wheat and pea-oats mixes, the cereals also produced their maximum yields in a monocultural form, and the inclusion of pea seed in the cereal seed and the increasing of pea seed density led to considerable reduction in the cereal yields (R = 0.988–0.993). At the maximum pea seed density, wheat yielded 3.8 times less and oats 2.2 times less than in their monocultural form. It was observed that pea tends to be less competitive with cereals than vetch, for the yield decreases were smaller than those of the cereals grown in a mix with vetch. Oats produced higher yields than wheat in both a monoculture and a mix.

Table 2. Yield formation in cereal monocultures and in pea-cereal mixes at different pea seed densities and a comparison of different trial series (two-year averages, kg ha^{-1})

Seeding rate of pea, seeds per m^{-2}	Pea + wheat, yield (check)	Pea + oats	
		yield	difference
	yield of cereals		
0	2172	2813	641
20	1832	2670	838
40	1522	2484	962
60	1240	2254	1014
70	1109	2123	1014
80	986	1980	994
90	870	1827	957
100	761	1662	901
120	564	1301	737
	$LSD_{95\%}$		95
	yield of pea		
20	860	714	-146
40	1373	1106	-267
60	1777	1442	-335
70	1938	1590	-348
80	2072	1723	-349
90	2178	1843	-335
100	2258	1949	-309
120	2334	2119	-215
	$LSD_{95\%}$		61
	total yield of pea-cereals mixes		
20	2443	3103	660
40	2671	3348	677
60	2811	3479	668
70	2847	3501	654
80	2862	3495	633
90	2853	3461	608
100	2824	3398	574
120	2698	3185	487
	$LSD_{95\%}$		78

The productivity of pea in a mix with cereals was high already at smaller pea seed densities (Table 2). At the pea seed density of 20 germinating seeds per m^{-2}, pea yielded between 710–860 kg ha^{-1}; nevertheless, this is approximately 2 times smaller than the yield of vetch at the same seed density. This shows that at smaller legume seed densities the competitiveness of cereals is greater with pea than with vetch. At greater pea seed densities the competitiveness of cereals with pea decreases. In a mix with cereals, pea produced the maximum yield (2120–2330 kg ha^{-1}) at the maximum seed density (120 germinating seeds per m^{-2}). In a mix with oats, the yield of pea was reliably smaller than in a mix with wheat.

The maximum yields of the pea-wheat mixes (2550–2560 kg ha^{-1}) were obtained at pea seed densities of 70–90 germinating seeds per m^{-2}, and the yields of the pea-oats mixes were at their maximum (3480–3500 kg ha^{-1}) at the pea seed densities of 60–80 germinating seeds per m^{-2}.

Generalising the data for wetter growth sites, the recommended pea seed density in pea-cereal (wheat or oats) mixes might be 60–70 germinating seeds per square metre.

One of the reasons for the reduction in cereal yields might be the reduction in the 1000 seed weight of wheat and oats due to the inclusion of legumes in crops and to the increasing of legume seed densities (Table 3).

Table 3. Cereal 1000 seed weights in different combinations depending on legume seed densities (two-year averages, g)

Seeding rate of legumes, seeds per m^{-2}	Vetch + wheat	Vetch + wheat + N_{50}	Vetch + oats	Pea + wheat	Pea + oats
0	28.8	27.8	37.6	32.4	33.9
20	23.8	23.1	34.9	31.9	33.6
30	21.9	21.4	33.7	31.7	33.4
40	20.3	20.1	32.5	31.4	33.2
50	19.1	19.2	31.3	31.2	32.9
60	18.4	18.8	30.2	30.9	32.6
70	18.0	18.7	29.2	30.6	32.2
100	19.0	21.1	26.5	29.8	30.9
120	21.6	24.8	24.9	29.2	29.8

When wheat was mixed with vetch, which in the high-precipitation years occupied the upper storey, the wheat 1000 seed weight reduced even by more than 10 grams, and the correlations between vetch seed densities and cereal 1000 seed weights were very strong (R = 0.958–0.966). When the cereals were mixed with pea, which has a shorter stem and therefore proves less competitive with cereals, the 1000 seed weights of the cereals experienced smaller reductions: wheat by 3.2 g at the maximum and oats by 4.1 kg at the maximum. Yet even in pea-cereal mixes the correlations between the pea seed densities and the cereal 1000 seed weights were very strong and reliable (R = 0.871–0.923).

Conclusions

In a high-precipitation year, the yields of legumes grown in a mix with wheat or oats were high already at low seed densities. At the legume seed density of 20 germinating seeds per m^{-2}, the seed harvest of vetch was between 1420–1770 kg ha^{-1} and that of pea between 710–860 kg ha^{-1}. This also means that at lower seed densities the competitiveness of cereals was greater with pea than with vetch.

The inclusion of legumes in the crops and the increasing of legume seed density led to substantial reductions in the cereal yields. One of the reasons for the reductions in the yields was the formation of smaller grains in cereals, which was particularly evident in the vetch-cereal mixes.

Under no fertilisation the per-hectare yields of the vetch-wheat and vetch-oats mixes were greater than those of the cereal monocultures by 950 kg and 800 kg, respectively. The maximum yields in the wheat-vetch (2880 kg ha^{-1}) and oats-vetch (3800 kg ha^{-1}) mixes were obtained at the vetch seed densities of 40–60 and 30–50 germinating seeds per square metre, respectively. As well, the yields of the cereal-pea mixes were considerably higher than those of the monocultures of either species; however, the maximum yields of the cereal-pea mixes were approximately 300 kg ha^{-1} smaller than those of the cereal-vetch mixes.

Generalising the results of the research for wetter growth sites, mixed crops should be set up on wetter growth sites by including vetch seed in the wheat or oats seed at the rate of 30 germinating seeds per m^{-2} and pea seed in the same at the rate of 60–70 germinating seeds per m^{-2}. On a wetter growth site the vegetative growth of legumes, particularly vetch, is very intensive and their competitiveness with cereals is great.

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ON THE EFFECT OF NITROGEN FERTILIZER ON MIXED SEEDINGS OF COMMON VETCH (*Vicia sativa* L.) AND WHEAT (*Triticum aestivum* L.).
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On the Effect of Nitrogen Fertilizer in Mixed Seedings of Common Vetch (*Vicia sativa* L.) and Wheat (*Triticum aestivum* L.)

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The study carried out in the experimental fields of the Department of Field Crop Husbandry of the Estonian Agricultural University in 2000 and 2001 showed that N-fertilizer had a positive effect on the total yield of mixed seeding of common vetch and wheat. Application of N-fertilizer in mixed seedings was appropriate only in the aspect of total yield, while no positive changes were revealed in the aspect of protein yield. The protein content in dry matter of vetch seeds was 30% and the use of nitrogen fertilizer did not influence the protein content of vetch. The protein content of wheat seeds was significantly affected by the proportion of vetch in the seed mix.The effect of nitrogen fertilizer had a considerably weaker effect on the protein content of wheat seeds.

Wheat, vetch, mixed crop, yield, protein.

Introduction

Our previous studies [1] showed that vetch-wheat mixed crops planted after both cereals and potato produced a greater yield than the monocultures of the same species. This phenomenon was particularly apparent in no N-fertilisation variants. N-fertilisation (N_{34}) led to mixed crops having a relatively small advantage over cereal monocultures. It is important to note, however, that in a vetch-wheat mix under no N-fertiliser the protein content of the yield as well as the protein yield itself were considerably higher than those in an N-fertilised wheat monoculture.

As vetch-wheat mixes produced relatively high seed and protein yields under no N-fertilisation, these crops were recommended for organic farming. Even under conventional farming, vetch-wheat mixes need not necessarily be N-fertilised. This would help save on fertilisation expenses and reduce the burden on nature [2].

This research aimed to check the effect of N-fertiliser on vetch-wheat mixes if compared to vetch and wheat monocultures. In addition, one more series were added to the trial in which a somewhat greater level of N-fertiliser was used.

Conditions and methods

The research was conducted in 2000 and 2001 as a three-series trial. The variants in the trial series were identical; they are given in Table 1. The trial series were as follows: Series 1 – the variants were established on no-N-fertiliser soil; Series 2 – the variants were established on N_{34}-fertilised soil; and Series 3 – the variants were established on N_{68}-fertilised soil. The N-fertiliser used was ammonium nitrate. Pursuant to the methodology formulated at the Institute of Field Crop Husbandry [3], the trial series variants were established in one replication, except for the first variant, which was used on two trial plots (in two replications). Opting for one replication was based on the premise that data processing would involve regression analysis, which enabled the calculation of trial error in the series even from one replication.

Table 1. Variants used in series of experiment
***1 lentelė**. Bandymo variantai*

No of variant *Varianto Nr.*	Seeding rate, germinating seeds per one m^2 *Pasėlio proporcijos, sudygusių sėklų m^2*		
	vetch *vikiai*	wheat *kviečiai*	total *iš viso*
1a	100	0	100
1b	100	0	100
2	90	50	140
3	80	100	180
4	70	150	220
5	60	200	260
6	50	250	300
7	40	300	340
8	30	350	380
9	20	400	420
10	10	450	460
11	0	500	500

The field trials were conducted in the experimental fields of the Institute of Field Crop Husbandry of the Estonian Agricultural University at Eerika. The fields had pseudopodzolic soils, which according to the international WRB system was called *Albeluvisols* [4]. Phosphor and sodium fertilisers were not used in the trials, since the experimental soils need for P and K was small. In both years, the preceding crop was spring wheat fertilised with N_{60}.

The meteorological conditions in 2000 were favourable for cereal growth. The spring was characterised by a warm and low-precipitation period lasting until the 3rd decade of May. The amount of rainfall in that decade was higher by 40 mm compared to the long-time average. The first decades of July and August were cooler and more rainy than the long-time average. Towards the end of the vegetation period the weather turned warmer and drier again, which considerably facilitated mixed crop harvesting. The trial crops were harvested in on 28 August.

The May and June of 2001 were close to the many-years average in terms of air temperatures, whereas July was warmer than the average by 3°C. All the spring and summer months were rainier than the long-time average. In June, July and August the precipitation rate exceeded the average by 1.3-1.5 times. The abundant rainfall contributed to intensive vegetative growth of vetch, which ultimately exceeded wheat by 25-30 cm in length. Consequently, wheat was understoreyed in the mix. The trial crops were harvested in on 15 August.

After harvest, the yields were registered both separately by the components and as a total yield. Additionally, the 1000-seed weight was determined for both vetch and wheat. At the Plant Biochemistry Laboratory of the Estonian Agricultural University the N-content of the samples was determined, from which the protein contents of the yields as well as the protein yields were calculated.

The data was processed using regression analysis according to the following generalising equation:

$$y = a + bx + cx^2,$$

where y - is the arguments' function: yield, protein yield, 1000-seed weight, protein content (kg ha^{-1}; g; %);
a - is the absolute term (constant) of the equation;
b and c - are regression coefficients;
x - is the argument; in regression analysis the argument was taken to be the amount of germinating seeds per square metre (vetch + wheat), which ranged between 100-500.

In accordance with the methodology formulated [5], the confidence limits were calculated for all the regression equations at a 95% reliability rate ($CL_{95\%}$). To assess the reliability of the effect of N-fertiliser, the least significant differences were computed by adding up the confidence limits of the respective equations ($CV_{95\%I} + CV_{95\%II}$ or $CV_{95\%I} + CV_{95\%III}$) at a 95% reliability rate ($LSD_{95\%}$). Here, $CV_{95\%I}$ represented the confidence limits of the regression equation for unfertilised soil, $CV_{95\%II}$ - the confidence limits of the regression equation for the soil fertilised with a smaller amount of nitrogen (N_{34}) and $CV_{95\%III}$ - the confidence limits of the regression equation for the soil fertilised with a greater amount of nitrogen (N_{68}).

All the numerical values presented in the tables of this article were computed using regression equations. The reliability rate for all the regression equations on which the calculations were based was higher than 99 %.

Results

The research resulted in determining the yields of the mixed crop components in both monocultural and mixed variants and of vetch-wheat mixes established at different seed mix ratios as well as of the influence of N-fertilisation on the yields (Table 2). On unfertilised soil, the yield of monocultural wheat was considerably higher than that of monocultural vetch. N-fertiliser led to even greater differences in yield, since N-fertilisation had a negative effect on monocultural vetch whereas it significantly boosted the two-year average yields of monocultural wheat. Interestingly, the conditions for wheat growth on unfertilised soil were similar in both years of the trial. On no-fertiliser soil, wheat monoculture yielded 3.380 kg ha^{-1} in 2000 and 3.360 kg ha^{-1} in 2001. This also meant that the wheat yield in either trial year was relatively high for unfertilised soil. Our previous studies showed that under similar conditions, wheat yields were close to 2.000 kg ha^{-1} [1]. The effect of N-fertilisation on wheat yield was greater in 2000, when N_{68} increased the harvest by 1.000 kg per hectare. Averaged out over the two years, the mean efficiency of N_{68} fertiliser in wheat was 9.4 kg of grains per 1 kg of nitrogen.

The conditions for vetch growth, however, differed by year. The rainy year of 2001 was advantageous to vetch - its monoculture yielded 2.460 kg ha^{-1} on unfertilised soil. Under similar conditions in 2000, however, vetch yielded 1.375 kg of seed per hectare. A negative effect of N-fertilisation on vetch seed yield in both monocultural and mixed variants was evidenced in 2001, the very year favourable to vetch growth. In its monocultural form, vetch seed yields for that year dropped by 150-200 kg per hectare, depending on the amount of the fertiliser applied. In mixed crops, the negative effect of N-fertilisation on vetch seed yield was even greater than in monocultural variants, and increased proportionally to the decrease in the share of vetch in the seed mix. The reason may be increased competitiveness of wheat, since the effect of N-fertilisation on the wheat component of the mix was positive.

Vetch-wheat mixes produced considerably greater yields than vetch monocultures. The yields were in direct dependence on the amount of seed sown and the ratio of the seed mix components. The correlation between the amounts of seed sown in a mixed crop and the respective yields was very close, with the numerical values of the correlation coefficients (R) ranging between 0.968-0.966 depending on the availability of nitrogen. In this research, a vetch-wheat mix did not have any significant advantage over a wheat monoculture in terms of the yield. On unfertilised soil, mixed crops produced somewhat greater yields than wheat monocultures provided the proportion of vetch in the seed mix was 12 germinating seeds per m^2. Under N-fertilisation, however, the yields of mixed crops were smaller than those of wheat monocultures on all the cases.

Table 2. The formation of wheat and vetch monocultural and mixed crops depending on the amount of seed sown and on nitrogen availability as averaged over two years.
***2 lentelė**. Kviečių ir vikių monokultūros formavimasis,mišinio derlius, priklausomai nuo pasėtų sėklų kiekio ir azoto normos (dvejų metų vidurkis)*

Seeding rate, seeds per one m^2 vetch + wheat = total *Pasėlio proporcijos sėklų m^2 vikiai + kviečiai = bendras*	Without nitrogen fertiliser *Be azoto trąšų*	Influence of *Poveikis*	
		N_{34}	N_{68}
	Yield of vetch, kg ha^{-1} *Vikių derlius kg ha^{-1}*		
100 + 0 = 100	1919	-87	-65
76 + 124 = 200	1795	-119	-155
64 + 186 = 250	1665	-146	-200
50 + 250 = 300	1490	-180	-245
38 + 312 = 350	1271	-221	-290
25 + 375 = 400	1006	-269	-335
12 + 438 = 450	696	-324	-380
	LSD_{05} *R_{05}*	42	79
	Yield of wheat, kg ha^{-1} *Kviečių derlius kg ha^{-1}*		
76 + 124 = 200	673	294	292
64 + 186 = 250	1082	343	498
50 + 250 = 300	1508	373	645
38 + 312 = 350	1949	385	733
25 + 375 = 400	2407	377	761
12 + 438 = 450	2880	351	730
0 + 500 = 500	3370	306	639
	LSD_{05} *R_{05}*	59	126
	Total yield of mixed seeds, kg ha^{-1} *Sėklų mišinio derlius kg ha^{-1}*		
76 + 124 = 200	2502	120	158
64 + 186 = 250	2761	163	265
50 + 250 = 300	2987	189	352
38 + 312 = 350	3179	197	418
25 + 375 = 400	3339	188	464
12 + 438 = 450	3466	161	489
	LSD_{05} *R_{05}*	106	147

Our previous studies of a similar effect [1] showed that on unfertilised soil vetch-wheat mixes yielded far greater crops than wheat monocultures; however, the monocultural wheat yields were considerably smaller (2.000 kg ha^{-1}) than those observed in this study. Additionally, it appeared then that attempts to raise wheat monoculture yields to 3.000 kg ha^{-1} by using N-fertilisation resulted in a considerably lower productivity of mixed crops. Consequently, when wheat monoculture yields exceeded the margin of 3.000 kg per hectare, vetch-wheat mixes lost their advantage over wheat monocultures. However, this rule applies only, when the preceding crop is a cereal.

Although N-fertilisation increased the yields of vetch-wheat mixes, its influence on mixed crop yields was considerably smaller than it was on wheat monoculture yields. The reason was the opposite effect of nitrogen on the two mixed crop components, boosting the yield of wheat but reducing that of vetch.

Vetch 1000-seed weight evidenced considerable dependence on the amount of seed sown as well as on the ratio of the components in the seed mix (Table 3). On the soil with no N-fertiliser, the correlation between the amount of seed sown and vetch 1000-seed weight was very close (R = 0.938). Vetch 1000-seed weight was the smallest in the monocultural variant. In the mix with wheat, vetch 1000-seed weight was the greater the smaller the share of vetch in the seed mix. The effect of N-fertiliser on vetch 1000-seed weight was inconsistent. The less-nitrogen variant (N_{34}) increased 1000-seed weight in a vetch monoculture, whereas in a mixed crop at a relatively low share of vetch in the seed mix nitrogen had a negative effect on vetch 1000-seed weight. The effect of the more-nitrogen variant on vetch 1000-seed weight was unreliable.

Wheat 1000-seed weight in the trials was also heavily dependent on the amount of seed sown in a mixed crop and the ratio of one seed mix component to the other (in unfertilised soil R = 0.985). It peaked in a monocultural crop and decreased considerably in a mixed crop as the share of vetch increased in the seed mix. In a mixed crop the decrease of wheat 1000-seed weight was up to 6 g. The effect of N-fertiliser on wheat 1000-seed weight was positive, being one of the reasons behind the increase in wheat seed yield.

Table 3. The effect of the amount of seed sown, seed mix ratio and N-fertiliser on vetch and wheat 1000-seed weight as averaged over two years
3 lentelė. *Pasėtų sėklų kiekio, sėklų mišinio ir azoto trąšų įtaka kviečių ir vikių 1000 sėklų masei (dvejų metų vidurkis)*

Seeding rate, seeds per one m^2 vetch + wheat = total *Pasėlio proporcijos sėklų m^2 vikiai + kviečiai = bendras*	Without nitrogen fertiliser *Be azoto trąšų*	Influence of *Poveikis*	
		N_{34}	N_{68}
	1000-seed weight of vetch, g *Vikių 1000 sėklų masė g*		
100 + 0 = 100	60.4	0.0	0.0
76 + 124 = 200	66.3	0.6	1.0
64 + 186 = 250	68.5	-0.1	1.2
50 + 250 = 300	70.2	-0.9	1.3
38 + 312 = 350	71.4	-1.7	1.2
25 + 375 = 400	72.1	-2.6	1.0
12 + 438 = 450	72.3	-3.4	0.7
	LSD_{05} *R_{05}*	1.6	1.4
	1000-seed weight of wheat, g *Kviečių 1000 sėklų masė g*		
76 + 124 = 200	26.57	1.70	2.21
64 + 186 = 250	26.56	2.00	2.31
50 + 250 = 300	26.96	2.16	2.25
38 + 312 = 350	27.75	2.16	2.05
25 + 375 = 400	28.95	2.02	1.69
12 + 438 = 450	30.54	1.72	1.19
0 + 500 = 500	32.54	1.28	0.53
	LSD_{05} *R_{05}*	0.55	0.77

Vetch seed protein content changed insignificantly. The changes were caused by the N-fertiliser, the amount of seed sown and the ratio of the seed mix components, ranging in this study between 30.0-30.6% of dry matter. Data from Table 4 shows that wheat protein content depended significantly on the amount of seed sown and the ratio of the seed mix components, the correlation being very strong (R = 0.983-0.999). Wheat grain protein content was the lowest in the monocultural form and increased in a mixed crop, rising the higher the greater the share of vetch in a seed mix. The effect of N-fertiliser on wheat grain protein content was several times smaller than that of the amount of seed sown and, moreover, rather inconsistent. In monocultural wheat, the effect of nitrogen on wheat grain protein content was positive and depended on the amount of N-fertiliser. The larger amount of N-fertiliser resulted in a higher protein content in the yield. In a mix with a relatively high share of vetch seed, the effect of the smaller amount of N-fertiliser on wheat grain protein content was negative.

In our previous studies, considerable increase of wheat grain protein content was observed in mixes with vetch [6]. Logically, it should be considered that vetch improved nitrogen availability for its co-component, wheat, in a mixed crop. In reality, however, it was not the case. A research using a somewhat different methodology showed that wheat grown together with vetch took in less nitrogen from the soil (this cannot be shown by the methods used in this research). This was evidenced by the fact that the weight of nitrogen contained in the wheat grain yield obtained from a mix with vetch was less than that from a wheat monoculture, although the reverse was true for the relative content (percentage) of nitrogen in the yield [7]. In that research, the amount of wheat seed shown equalled that of vetch seed in both monocultural and mixed crops.

The considerably higher protein content of wheat grains when grown together with vetch pointed to keen competition between the species and, in particular, to the fact that in the second half of the vegetation period, or at least since the wheat flowering season, no-nitrogen extractives synthesis in wheat was rendered more difficult. As a consequence, when grown with vetch the share of protein compounds in wheat grains increased and the grains formed in wheat were considerably smaller. No-nitrogen extractives synthesis in wheat was inhibited due to the insufficient amount of photosynthetically active solar radiation reaching the lower leaves and stalk segments of wheat plants.

The protein content of the yields of vetch-wheat mixes was higher than that of wheat monocultures and lower than that of vetch monocultures, being in direct dependence on the share of vetch in the seed mix and in the yield (R = 0.999). The protein content in mixed crops was relatively high if compared to that in wheat monocultures even when the share of vetch in the seed mix was small. The effect of N-fertiliser on the protein content of a mixed crop yield was clearly negative, occasioned by the reduced share of vetch in the yield.

When grown as a monoculture on unfertilised soil, wheat protein content was considerably lower than the respective figure for monocultural vetch under the same conditions. Even the greater amount of nitrogen was unable to raise the protein content of monocultural wheat to the same level with monocultural vetch. Vetch-wheat mixes yielded considerably more protein than wheat monocultures, and also exceeded the protein yield of vetch monocultures at seed mix levels of 25 or more germinating vetch seeds per m^2.

Table 4. The effect of N-fertilisation and the amount of seed sown on wheat grain protein content and on the protein yields of the mixed crops and of the mixed crop components as averaged over two years
4 lentelė. *Azoto trąšų ir sėklų normos įtaka kviečių proteinų kiekiui mišinio ir mišinio komponentų proteinų derliui (dvejų metų vidurkis)*

Seeding rate, seeds per one m^2 vetch + wheat = total *Pasėlio proporcijos sėklų* m^2 vikiai + kviečiai = bendras	Without nitrogen fertiliser *Be azoto trąšų*	Influence of *Poveikis*	
		N_{34}	N_{68}
	Protein content of wheat grains, % in dry matter *Proteinų kiekis kviečių grūduose % sausoje medžiagoje*		
76 + 124 = 200	17.60	-0.71	-0.23
64 + 186 = 250	16.73	-0.62	-0.26
50 + 250 = 300	15.87	-0.49	-0.17
38 + 312 = 350	15.00	-0.31	0.03
25 + 375 = 400	14.15	-0.09	0.34
12 + 438 = 450	13.29	0.18	0.77
0 + 500 = 500	12.44	0.50	1.30
	$LSD_{95\%}$ *R_{05}*	0.27	0.38
	Protein content of mixed seeds, % in dry matter *Mišinio proteinų kiekis % sausoje medžiagoje*		
76 + 124 = 200	26.96	-1.21	-1.34
64 + 186 = 250	25.11	-1.50	-1.78
50 + 250 = 300	23.10	-1.63	-1.93
38 + 312 = 350	20.93	-1.60	-1.80
25 + 375 = 400	18.60	-1.41	-1.38
12 + 438 = 450	16.11	-1.06	-0.68
	LSD_{95} *R_{05}*	0.30	0.41
	Protein yield of wheat, kg ha^{-1} *Kviečių proteinų derlius kg ha^{-1}*		
76 + 124 = 200	95	36	38
64 + 186 = 250	145	42	63
50 + 250 = 300	193	46	82
38 + 312 = 350	239	48	95
25 + 375 = 400	284	48	102
12 + 438 = 450	327	45	103
0 + 500 = 500	369	39	98
	$LSD_{95\%}$ *R_{05}*	6	13
	Protein yield of vetch, kg ha^{-1} *Vikių proteinų derlius kg ha^{-1}*		
100 + 0 = 100	502	-23	-17
76 + 124 = 200	469	-31	-40
64 + 186 = 250	435	-38	-51
50 + 250 = 300	389	-46	-62
38 + 312 = 350	331	-57	-74
25 + 375 = 400	262	-69	-85
12 + 438 = 450	181	-83	-96
	$LSD_{95\%}$ *R_{05}*	11	21
	Total yield of protein, kg ha^{-1} *Bendras proteinų derlius kg ha^{-1}*		
76 + 124 = 200	571	-6	-5
64 + 186 = 250	584	-5	2
50 + 250 = 300	582	-4	11
38 + 312 = 350	565	-4	20
25 + 375 = 400	531	-5	30
12 + 438 = 450	482	-7	42
	$LSD_{95\%}$ *R_{05}*	21	24

The effect of N-fertiliser on the protein yields of wheat was positive in both the monocultural variants and the mixes with vetch. Its effect on vetch protein yields, however, was negative. The smaller amount of N-fertiliser had virtually no effect on mixed crop protein yields whereas the greater amount led to increased protein yields in mixed crops provided the share of vetch in both the seed mix and the yield was relatively small.

Conclusions

1. In this research, the conditions for wheat growth were favourable. Therefore, the yields of monocultural wheat considerably exceeded those of monocultural vetch on both unfertilised and N-fertilised soil. Due to the relatively high yields of wheat on unfertilised soil, in excess of 3,300 kg per hectare, vetch-wheat mixes had no significant advantage over wheat monocultures insofar as the yield was concerned.
2. The effect of N-fertiliser on the yields of the mixed crop components was different: it led to increased wheat yields and reduced vetch yields in both the monocultural and the mixed variants. Accordingly, the efficiency of N-fertiliser in vetch-wheat mixes remained relatively modest.
3. The 1000-seed weight of both vetch and wheat depended significantly on the ratio of the seed mix components. Increased vetch levels in the seed mix led to considerable losses in the 1000-seed weight of either mixed crop component. The effect of N-fertiliser on wheat 1000-seed weight was positive.
4. During the two years of research, vetch seed protein content remained stable, ranging within 30.0-30.6% of dry matter regardless of the amount of seed sown and fertilisation. Wheat protein content increased considerably in a mix with vetch proportionately to increased vetch levels in the seed mix. N-fertilisation of a vetch-wheat mix reduced the yield protein content, since nitrogen reduced the share of vetch in the yield.

Monocultural vetch yielded considerably more protein than monocultural wheat. The protein yields of vetch-wheat mixes were greater than those of the monocultures of the mixed crop components. In terms of protein yields, vetch-wheat mixes had a considerable advantage over wheat monocultures. N-fertilisation had virtually no effect on the protein yields of vetch-wheat mixes. Nevertheless, the yields were somewhat higher under the greater amount of N-fertiliser provided the share of vetch in the seed mix was relatively small.

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Azoto trąšų efektyvumas vikių (*Vicia sativa* L.) ir kviečių (*Triticum aestivum* L.) pasėlyje

Santrauka

Estijos žemės ūkio universiteto Augalininkystės katedroje 2000 – 2001 metais atlikti lauko bandymai parodė, kad azoto trąšų panaudojimas kviečių ir vikių pasėlio mišinyje tinkamas tik bendro sausos masės derliaus aspektu, kai nenustatyta teigiamų pasikeitimų proteinų derliaus aspektu. Mišinio pasėlio bendro derliaus padidėjimas nuo azoto trąšų įvyko dėl žymaus kviečių derliaus padidėjimo, kai vikių komponento su tręšimu sumažėjo. Azoto trąšų poveikis 1000 kviečių sėklų masei buvo teigiamas (padidėjo 2,2 g), kai 1000 sėklų vikių masė neparodė žymaus pokyčio. Bendro mišinio derliaus proteinų kiekis sumažėjo 1,6 – 1,9% su azoto trąšomis, nes sumažėjo vikių santykis derliuje. Proteinų kiekis vikių sėklų sausoje medžiagoje buvo 30 % ir azoto trąšų panaudojimas nelėmė vikių proteinų kiekio. Kviečių sėklų proteinų kiekis daugiau priklausė nuo vikių santykio pasėlyje. Azoto trąšos turėjo daug silpnesnį poveikį kviečių sėklų proteinų kiekiui.

Pasėlio mišinio proteinų derlius netręštoje dirvoje buvo apie 600 kg ha^{-1} ir žymiai neįtakojo azoto trąšų panaudojimas. Kviečių proteinų derlius panaudojus azoto trąšas (N68) pasiekė maksimumą - 467 kg ha^{-1}, kuris buvo daug mažesnis, palyginus su kviečių ir vikių mišinio proteinų derliumi netręštoje dirvoje.

Kviečiai, vikiai, mišinys, derlius, proteinai.

Gauta 2003 m. birželio mėn., atiduota spaudai 2004 m. rugsėjo mėn.

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Osalemine uurimisprojektides

Grandi projekti (nr. 1604) 'Eesti kasvutingimustele sobivate toiduteravilja sortide valik põhjamaades aretatud sortide seast koos agrotehniliste probleemide uurimisega', 1995–1996, põhitäitja.

Grandi projekti (nr. 2670)'Suviteraviljade, kaunviljade ning nende segukülvide kasvatamise optimaalsete teoreetiliste ja praktiliste lahendite väljaselgitamine', 1997–2000, põhitäitja.

Kasvufaktorite ja nende reguleerimisvõtete ning põllukultuuride produktsiooni ja saagi kvaliteedi vaheliste seoste uurimine lähtudes maa ratsionaalsest kasutamisest erinevates majandustingimustes, 1998–2002, põhitäitja (sihtfinantseeritav teema nr. 0170110s98).

Grandi projekti (nr. 4815) 'Mõningate biootiliste ja abiootiliste faktorite mõju suvitera– ja kaunviljade ning nende segukülvide produktiivsuse kujunemisele teoreetilistest ja praktilistest aspektidest lähtudes', 2001–2004, põhitäitja.

Erinevate taimekasvatus– ja maaviljelussüsteemide (s.h. loodussäästlike viljelusviiside) ning nende elementide teoreetiliste aluste uurimine optimaalsete praktiliste lahendite leidmiseks (sihtfinantseeritav teema nr. 0172616s03), 2003–2007, põhitäitja.

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Biosciences and Environment, Agricultural Sciences
Field crop husbandry

Grant funding and projects

Estonian Science Foundation (ESF) grant No. 1604 'Selection investigation of high–quality varieties pertinent to Estonian growing conditions', 1995–1996, (Principal investigator).

Optimal Theoretical and Practical Methods for the Cultivation of Spring Grains, Estonian Science Foundation (below ESF) grant No. 2670, duration 1997–2000: Identification of Legumes and their Mixed Seeds (Printcipal investigator).

Basic research project (national target–financed project): The Investigation of Growth Factors and their Regulation Methods to Influence Field Crop Production and Yield Quality in the Conditions of Different Economical Level. Project # 0170110s98, duration 1998–2002 (Principal investigator).

ESF grant No. 4815, duration 2001–2004: The Effect of Some Biotic and Abiotic Factors on the Productivity of Spring Cereals and Legumes and Their Mixed Crops from Theoretical and Practical Perspectives (Printcipal investigator).

Basic research project (national target–financed project): Investigation of Different Systems of Plant and Land Cultivation (incl. Environment Friendly Methods) as well as of the Theoretical Basis of their Elements for Finding Optimal Practical Solutions. Project No. 0172616s03, duration 2003–2007 (Printcipal investigator).

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